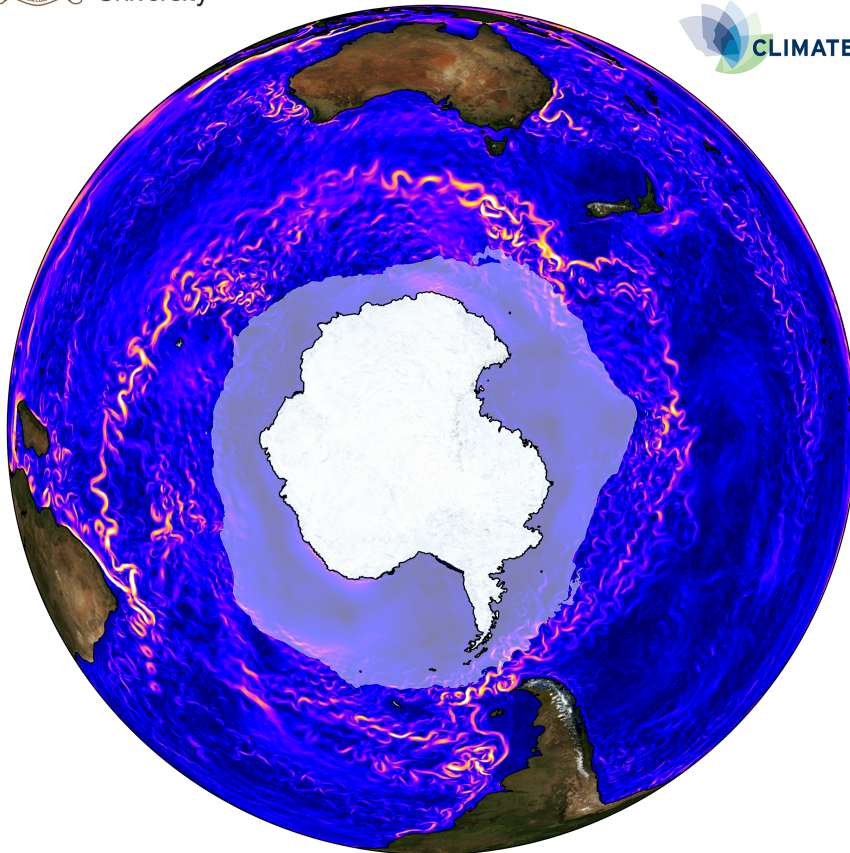


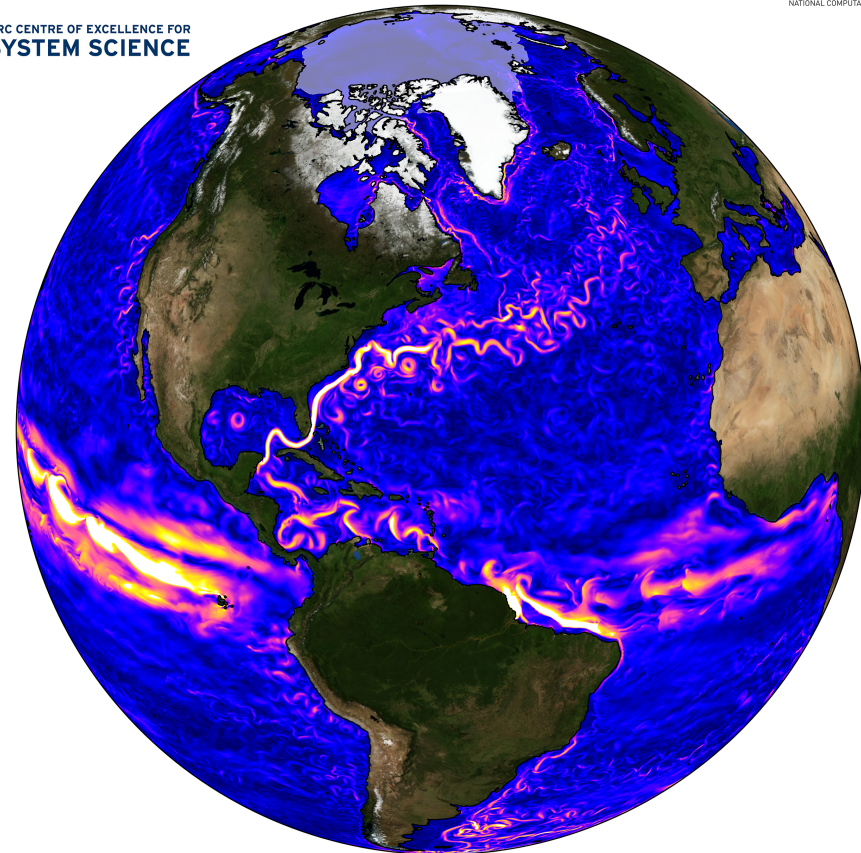
# Vertical resolution of global ocean models



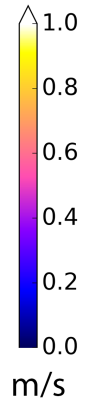
## Ocean Surface Current Speed in an Eddy-Resolving Model



Southern Ocean



North Atlantic Ocean

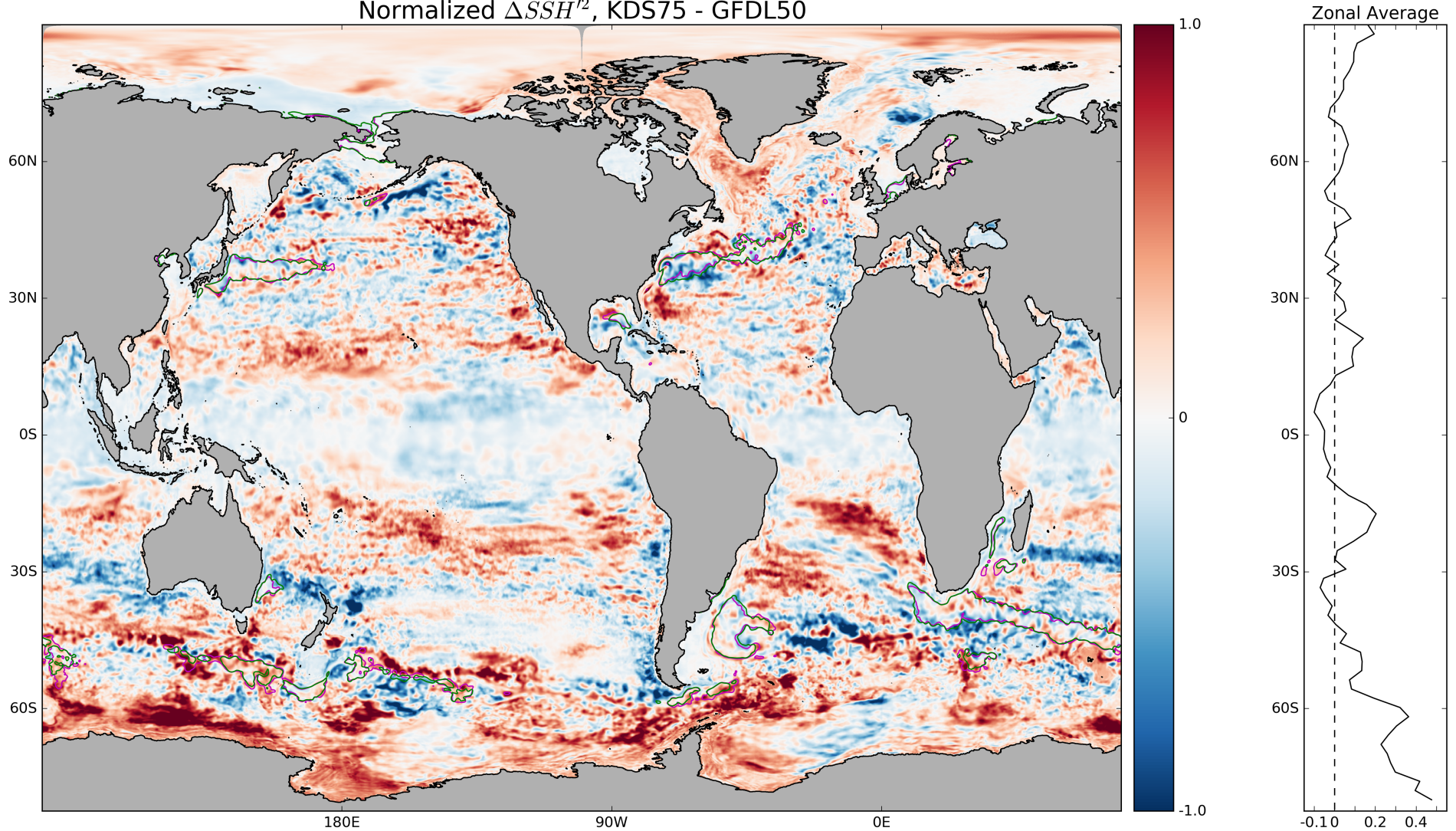


Kial Stewart, Andy Hogg, Steve Griffies, Aidan Heerdegen,  
Marshall Ward, Paul Spence & Matt England  
[kial.stewart@anu.edu.au](mailto:kial.stewart@anu.edu.au)

**MOM5-SIS**  
**ACCESS-OM 1/10°**  
**[www.cosima.org.au](http://www.cosima.org.au)**

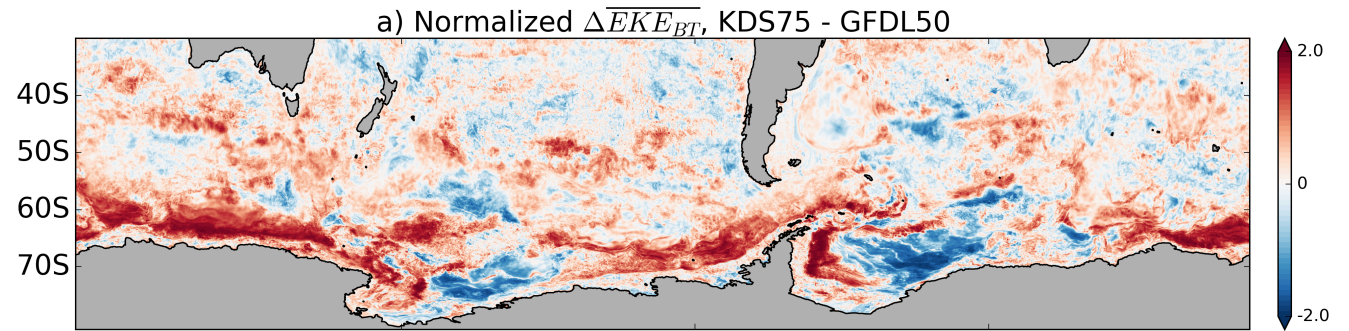
# Normalized sea surface height variability difference 75-level minus 50-level, 10-year daily

Normalized  $\overline{\Delta SSH^2}$ , KDS75 - GFDL50

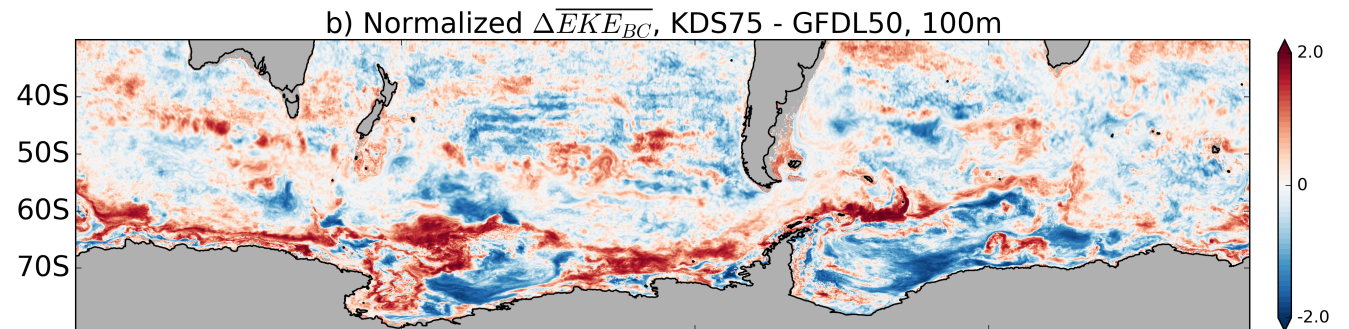


**5-year daily u,v  
75-level minus 50-level**

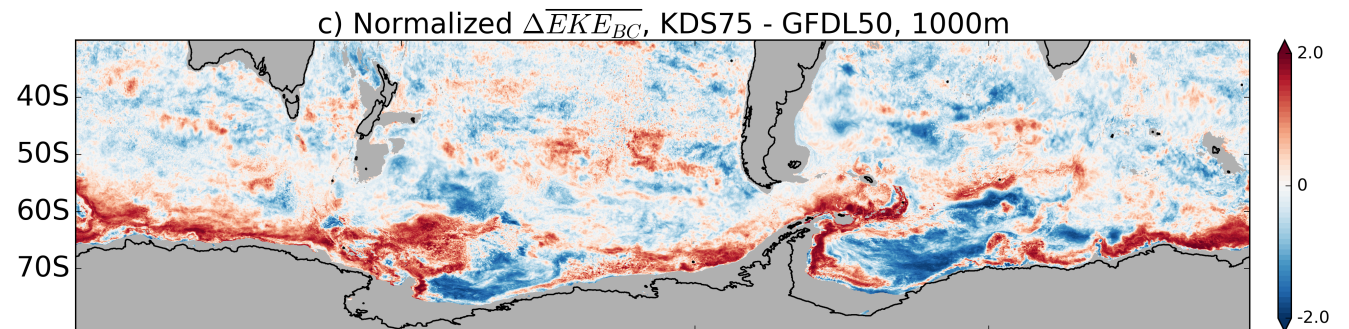
EKE barotropic  
difference



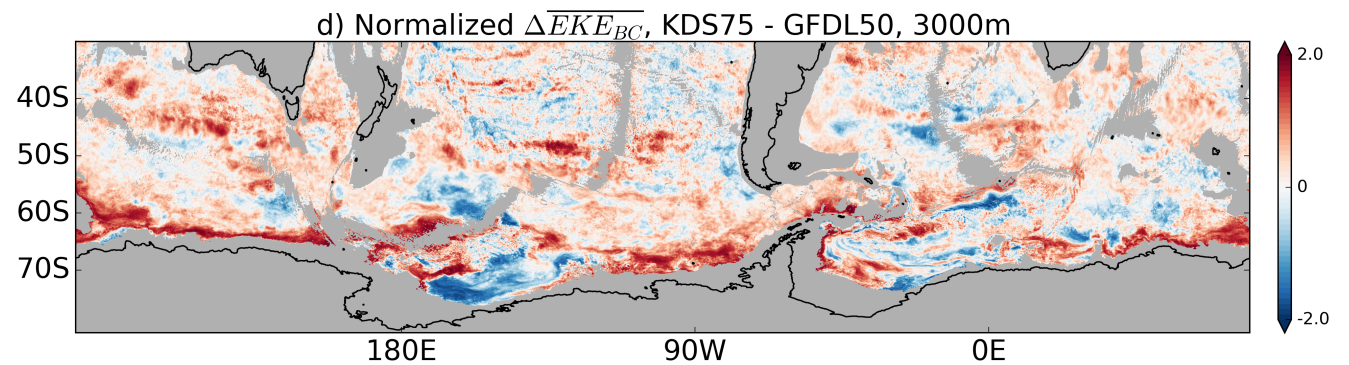
EKE baroclinic 100m  
difference



EKE baroclinic 1000m  
difference



EKE baroclinic 3000m  
difference



10-year mean

Overtuning streamfunction  
in density space: 50-level

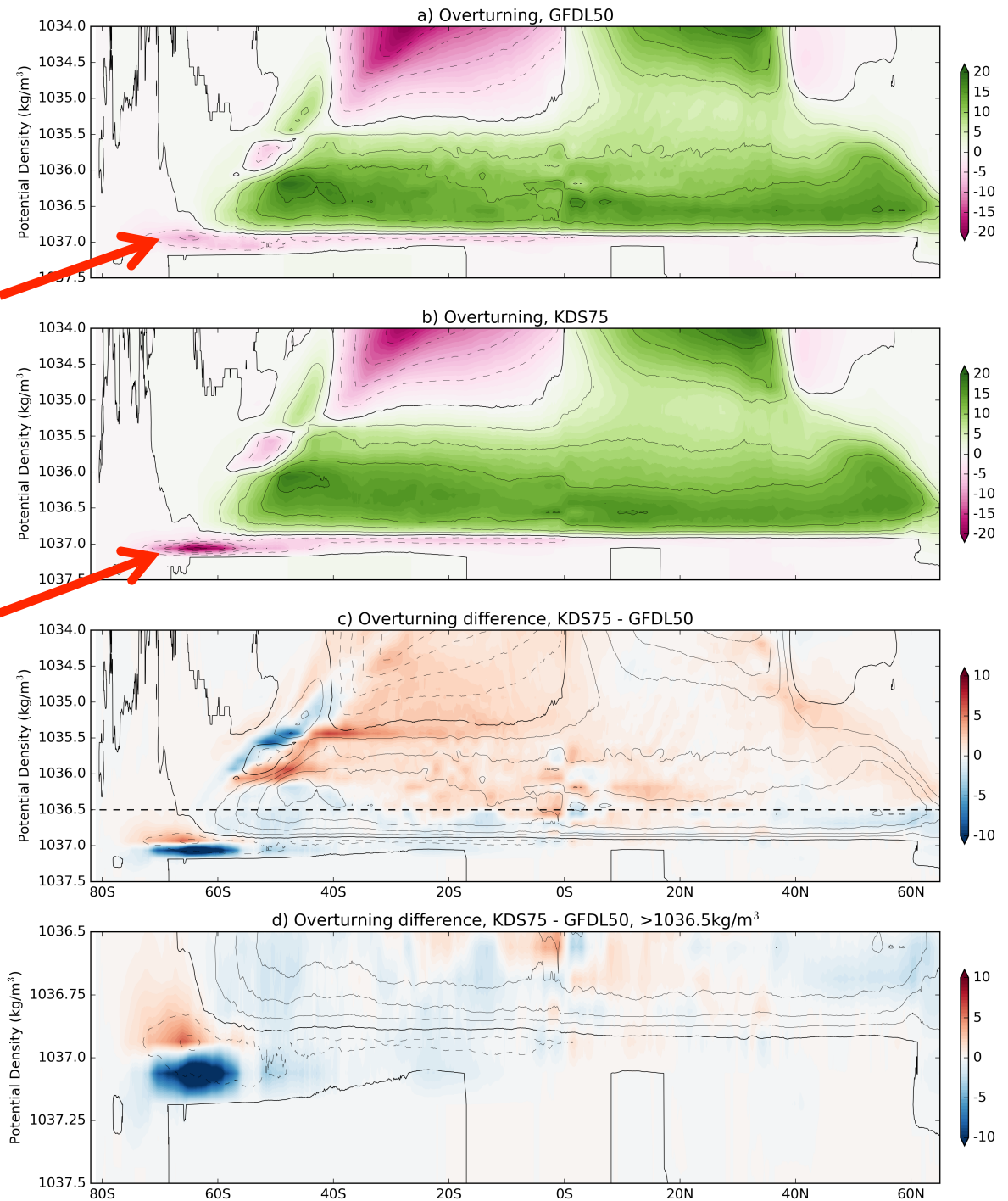
7Sv

Overtuning streamfunction  
in density space: 75-level

23Sv

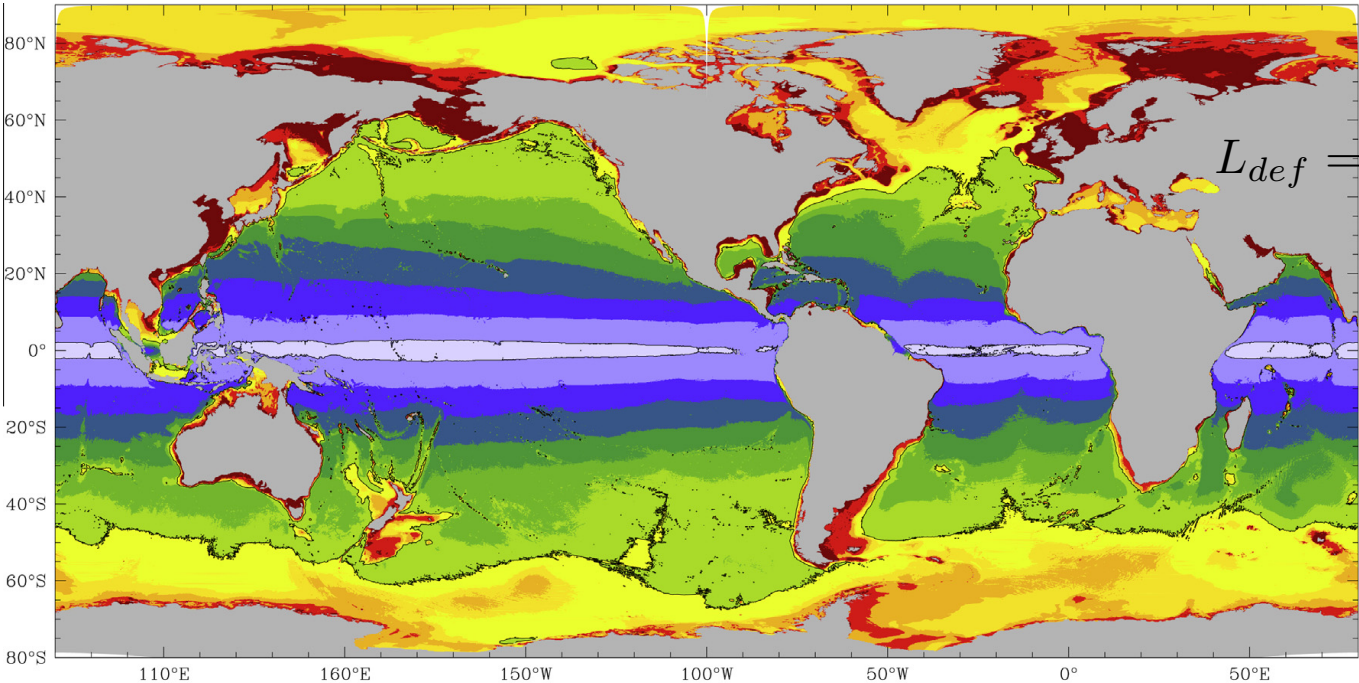
Overtuning streamfunction  
in density space: difference

75-level minus 50-level



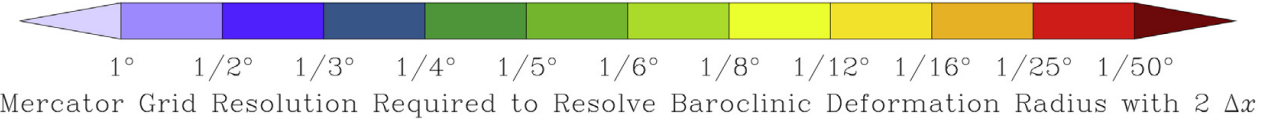
# Horizontal grid spacing required to ensure there are at least 2 grid points for the first baroclinic deformation radius

Hallberg (2013), *Ocean Modelling*



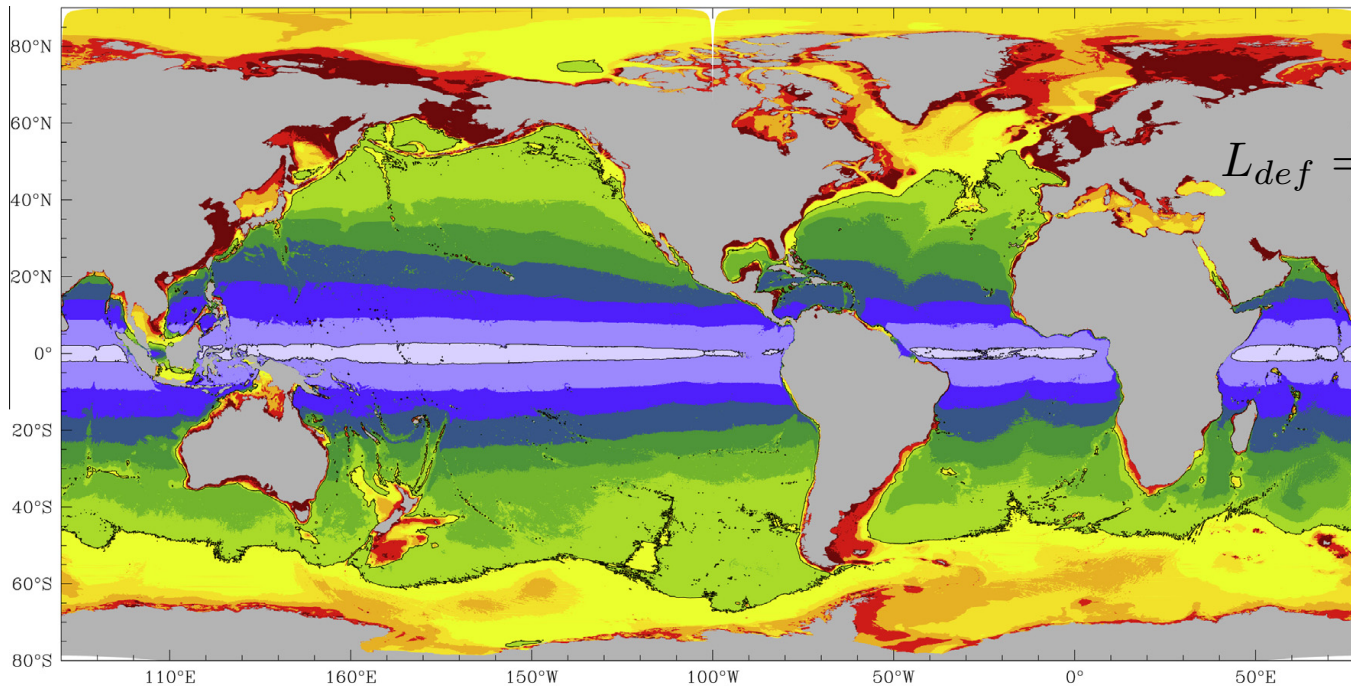
$$L_{def} = \sqrt{\frac{c_m^2}{(f^2 + 2\beta c_m)}}$$

$$\Delta x < a * L_{def}$$



# Horizontal grid spacing required to ensure there are at least 2 grid points for the first baroclinic deformation radius

Hallberg (2013), *Ocean Modelling*



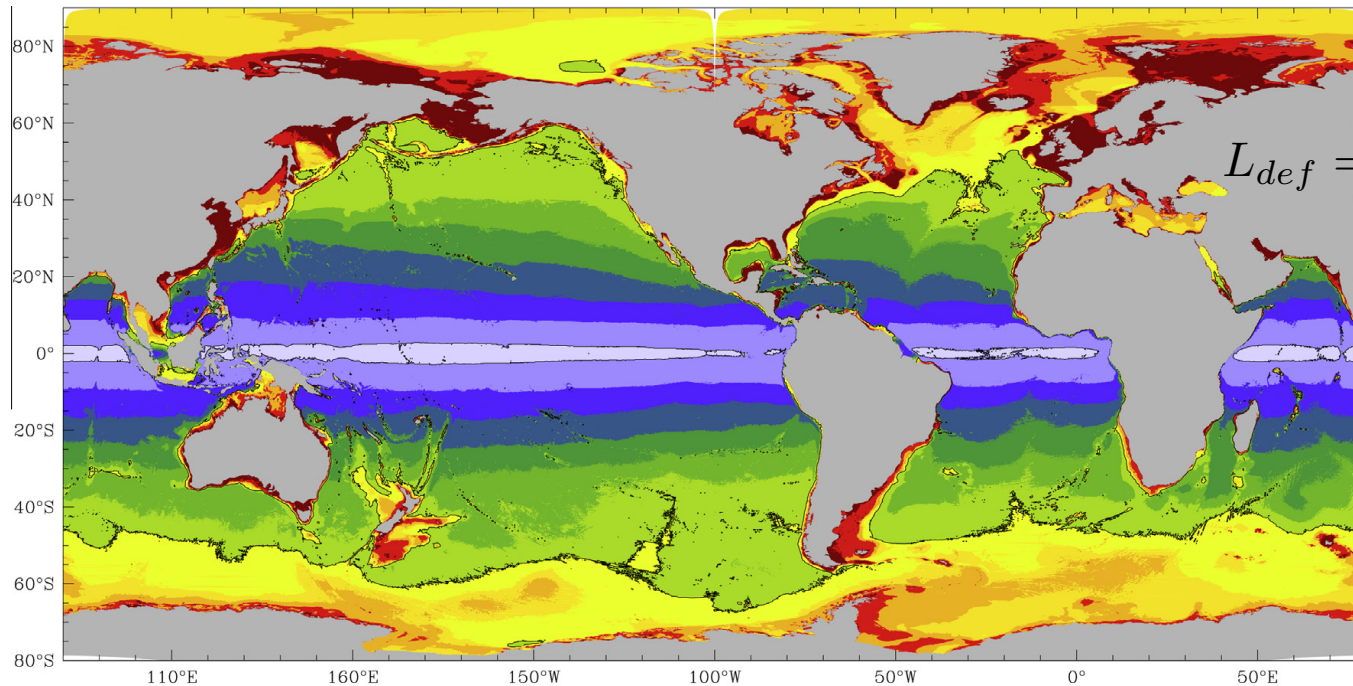
$$L_{def} = \sqrt{\frac{c_m^2}{(f^2 + 2\beta c_m)}}$$

$$\Delta x < a * L_{def}$$

**What vertical resolution is needed?**

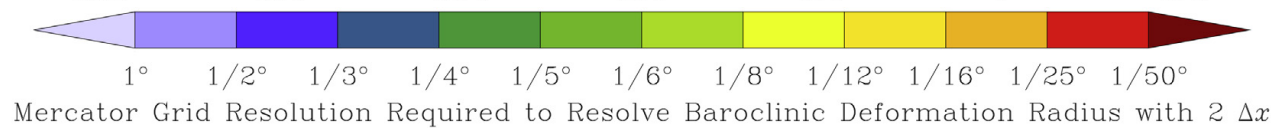
# Horizontal grid spacing required to ensure there are at least 2 grid points for the first baroclinic deformation radius

Hallberg (2013), *Ocean Modelling*



$$L_{def} = \sqrt{\frac{c_m^2}{(f^2 + 2\beta c_m)}}$$

$$\Delta x < a * L_{def}$$



## What vertical resolution is needed?

How do we know if the vertical grid is appropriate for the horizontal grid?

What vertical resolution is needed?

**The primary purpose of the vertical grid is to capture the vertical structure of horizontal flows.**

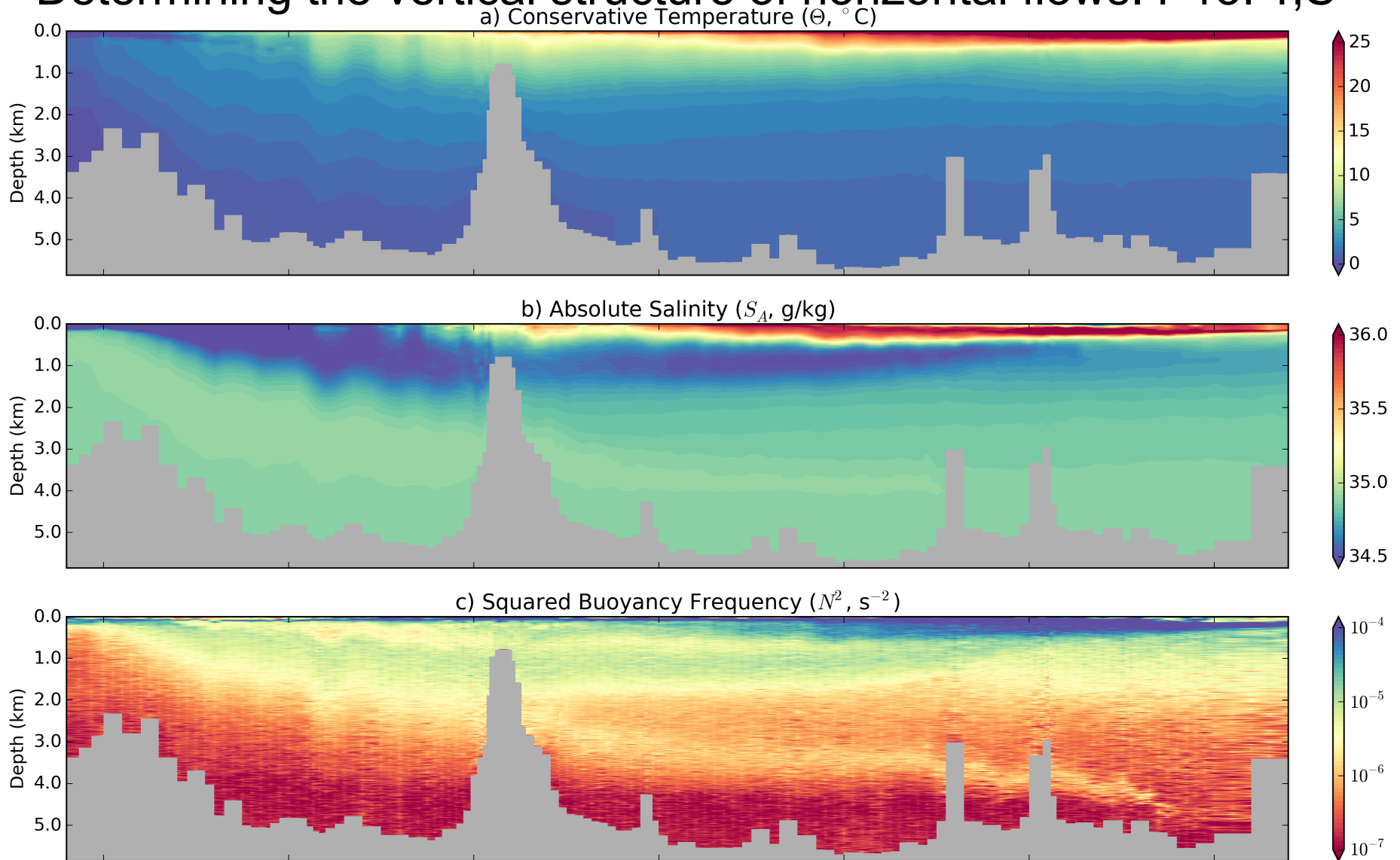


What vertical resolution is needed?

**The primary purpose of the vertical grid is to capture the vertical structure of horizontal flows.**

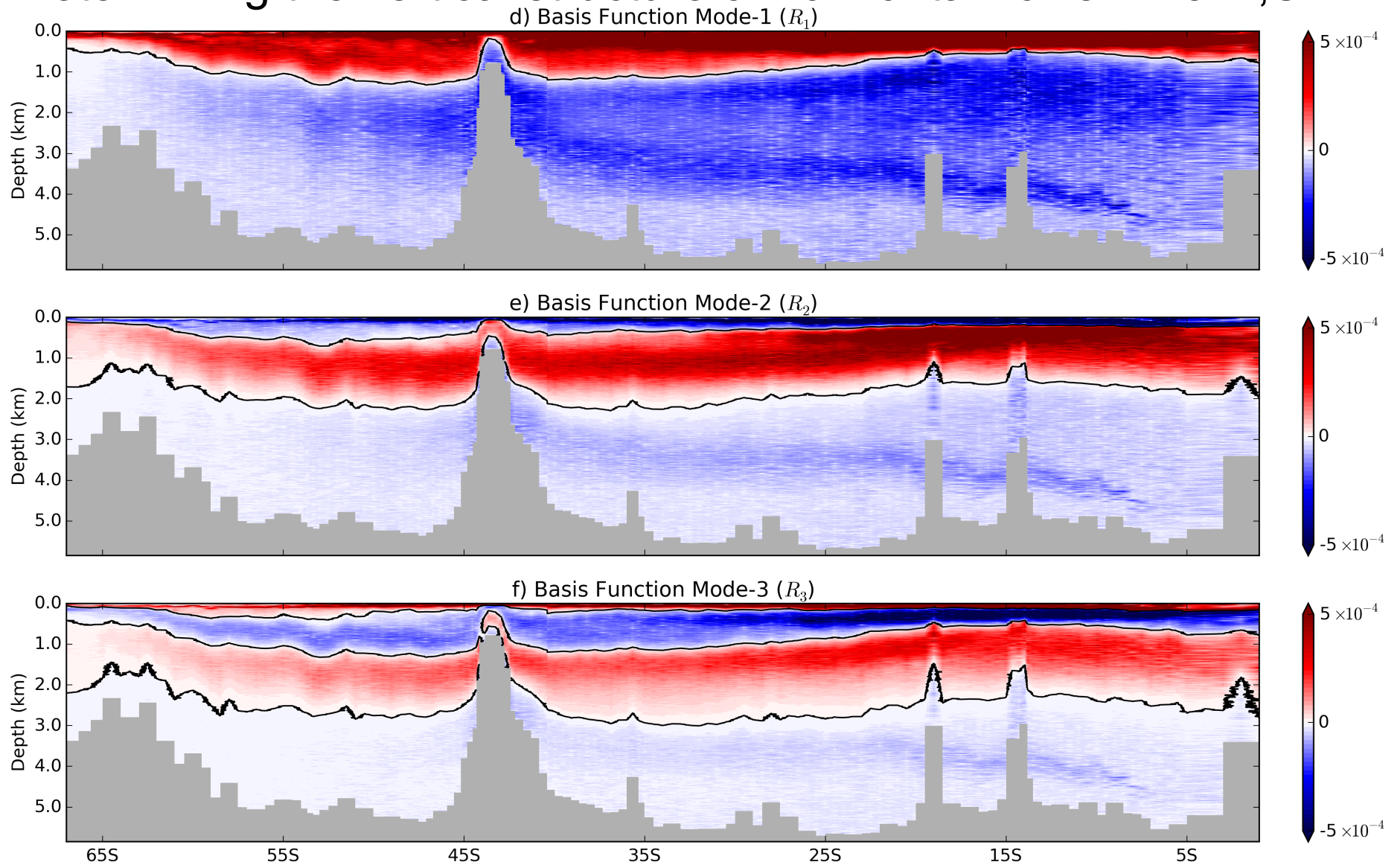
**The vertical structure of horizontal flows can be estimated from the baroclinic modal basis functions.**

# Determining the vertical structure of horizontal flows. P15: T,S



$$N^2 = g \left( \alpha \frac{\partial \Theta}{\partial z} - \beta \frac{\partial S_A}{\partial z} \right)$$

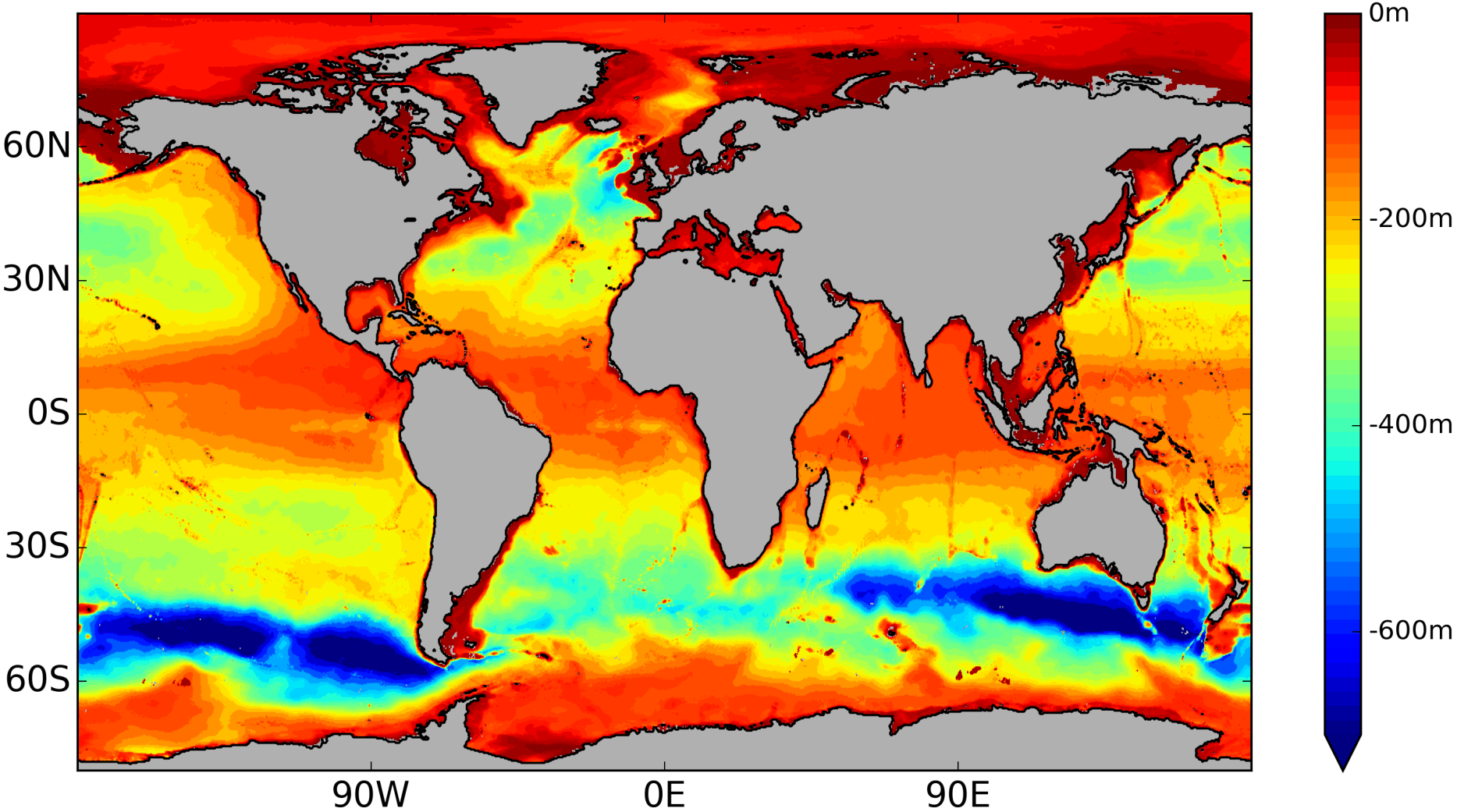
# Determining the vertical structure of horizontal flows. P15: T,S



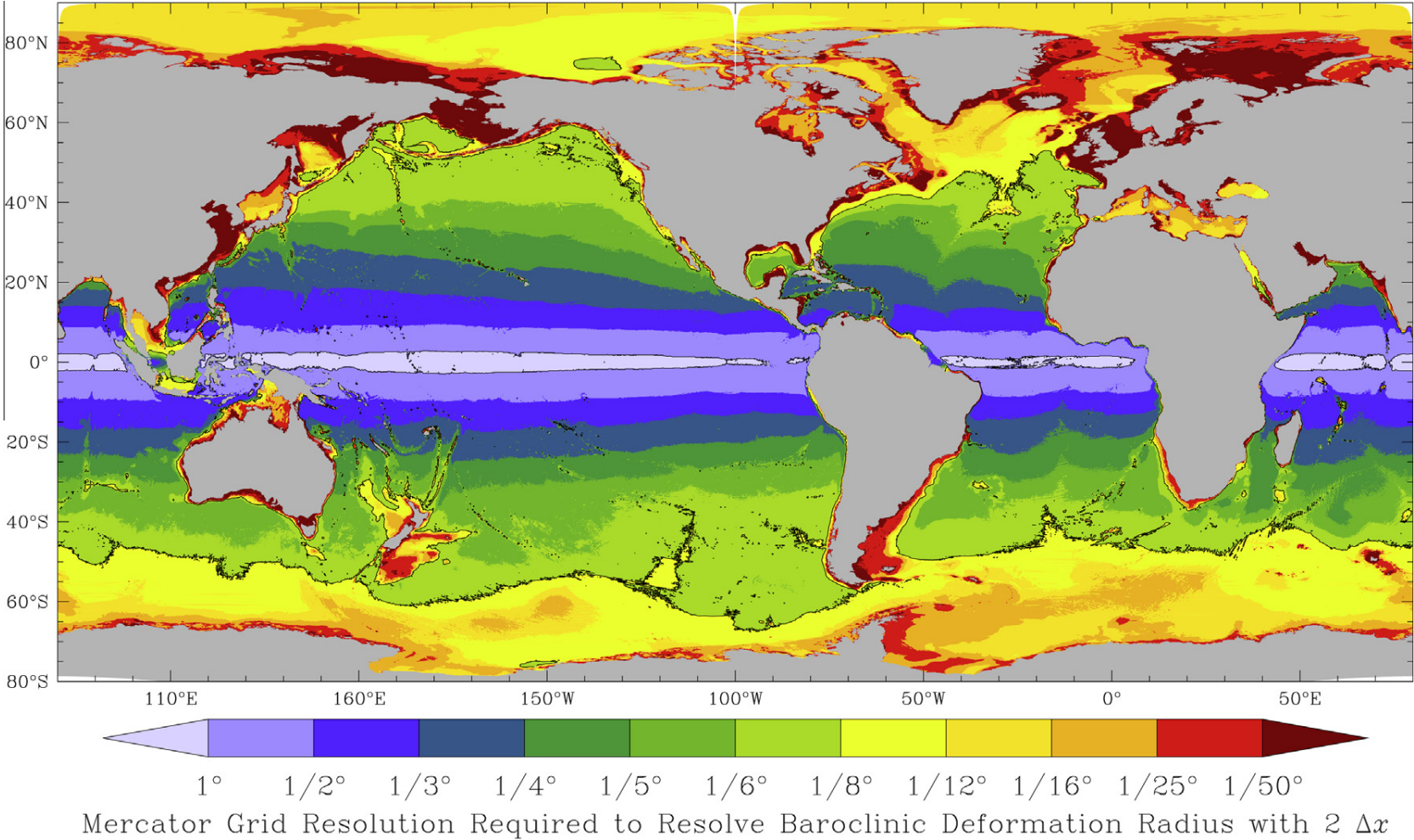
$$R_m(z) = - \left( \frac{c_m N(z)}{g} \right) \cos \left( \frac{1}{c_m} \int_{-H}^z N(z) dz \right)$$

# Zero crossing distribution: $h_{2,1}$

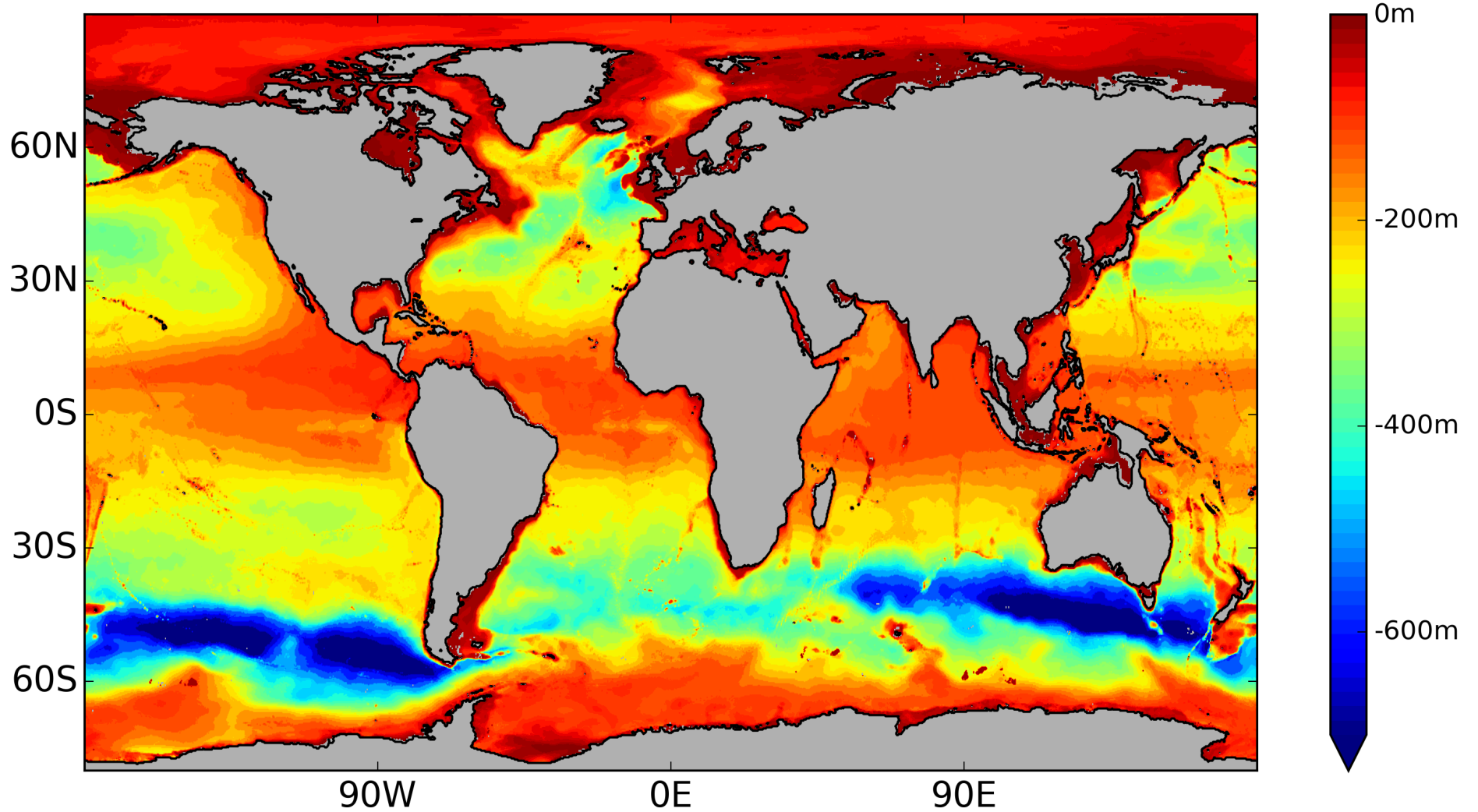
World Ocean Atlas 2013:  $h_{2,1}$



# Zero crossing distribution: $h_{2,1}$

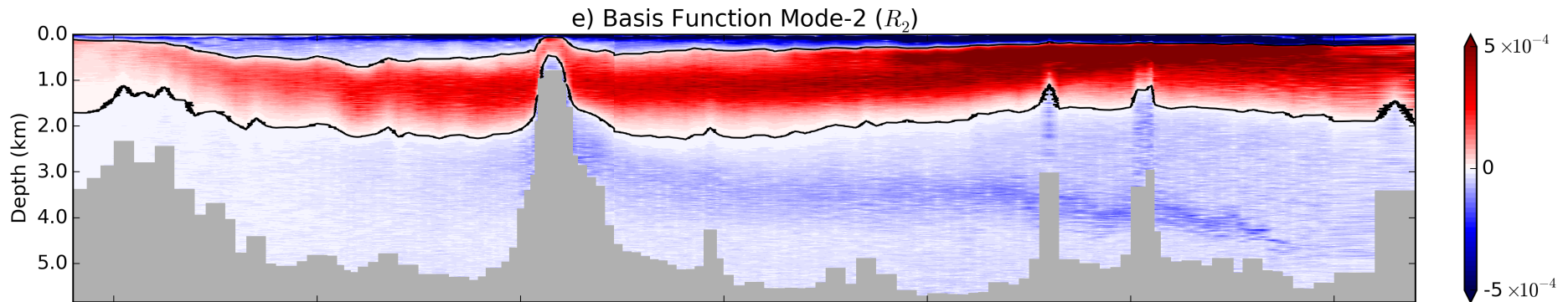


Zero crossing distribution:  $h_{2,1}$  – depth & stratification



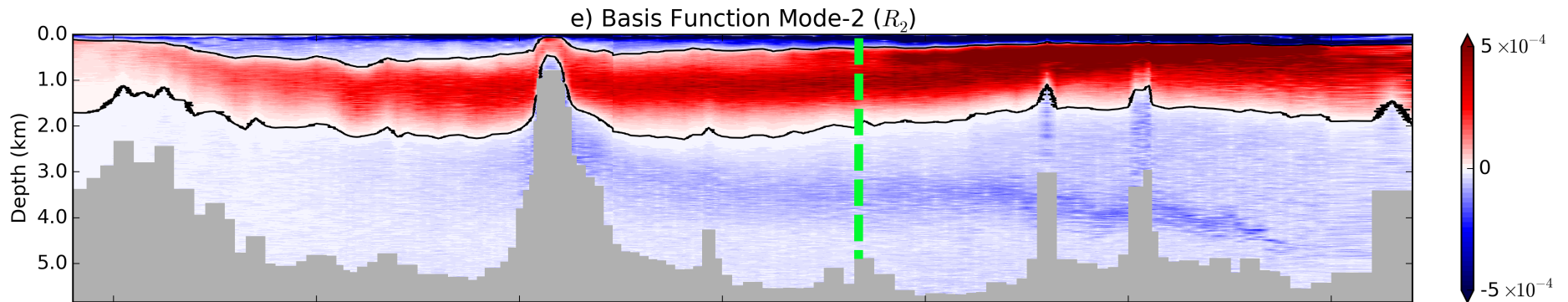
**Provides guidance for constructing vertical grids**

## Determining the vertical structure of horizontal flows. P15: T,S



Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings

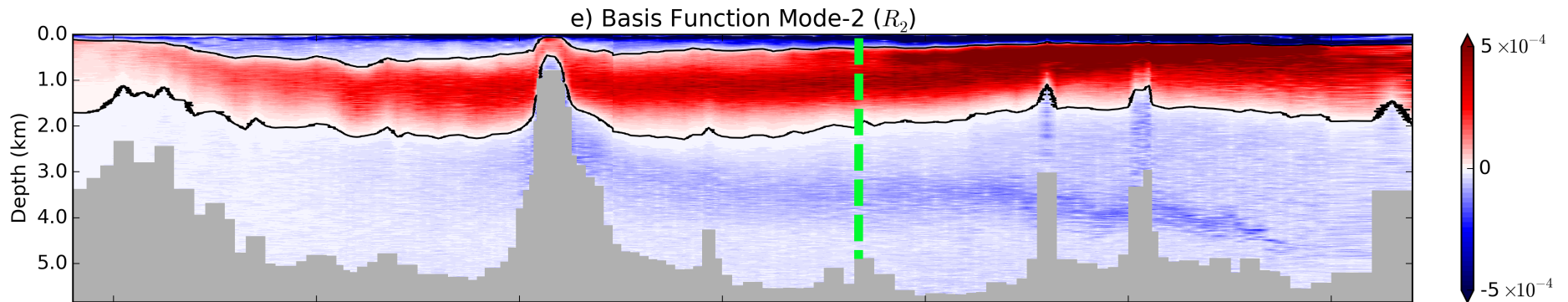
# Determining the vertical structure of horizontal flows. P15: T,S



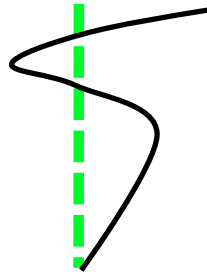
Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings



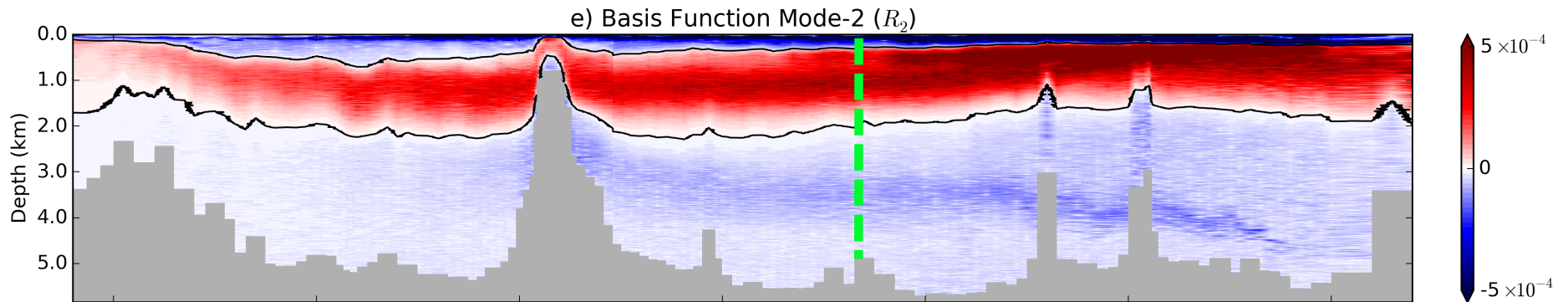
# Determining the vertical structure of horizontal flows. P15: T,S



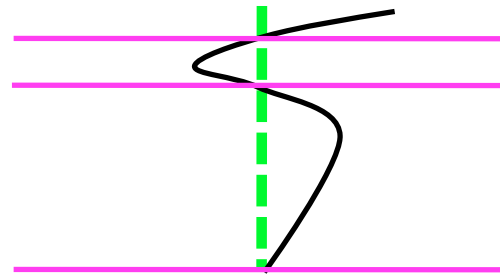
Ensure that  
there are 3  
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between zero  
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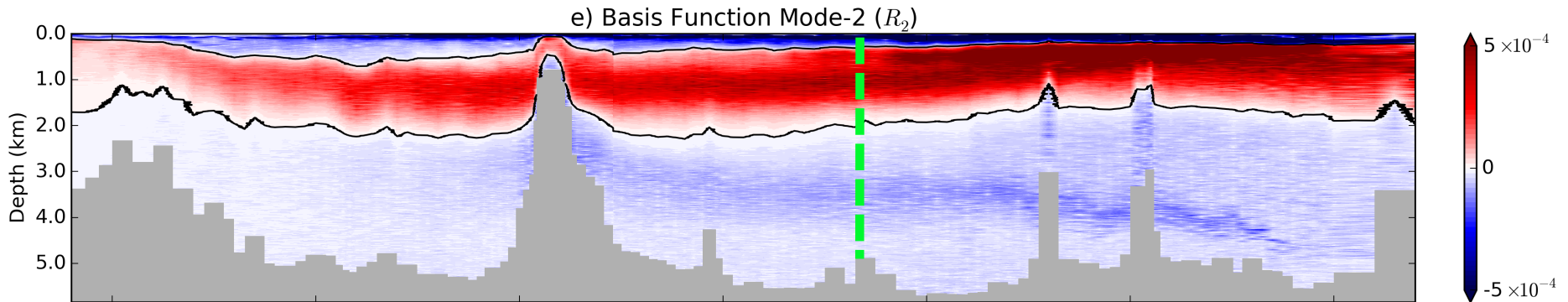
# Determining the vertical structure of horizontal flows. P15: T,S



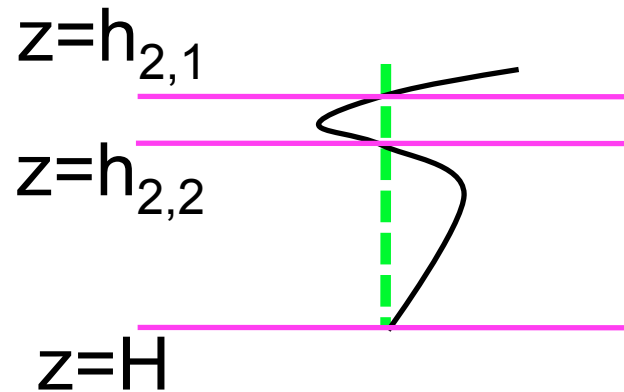
Ensure that  
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vertical grid  
points  
between zero  
crossings



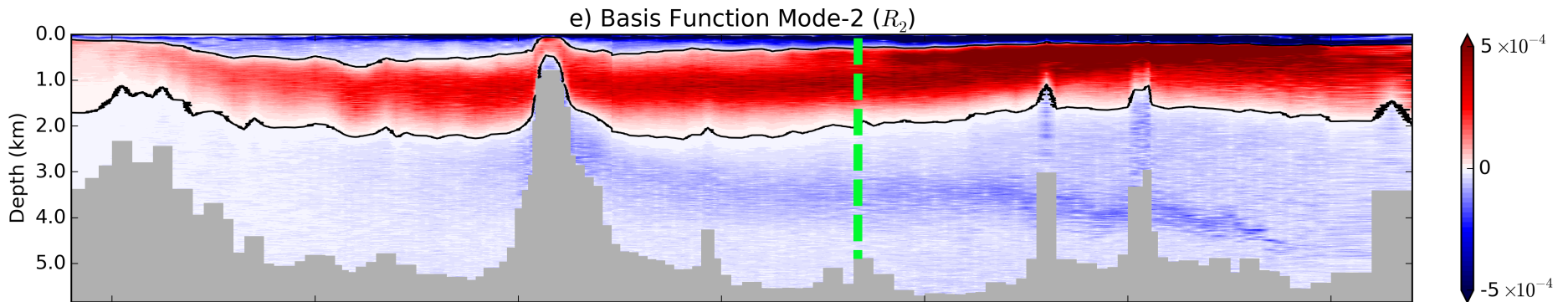
# Determining the vertical structure of horizontal flows. P15: T,S



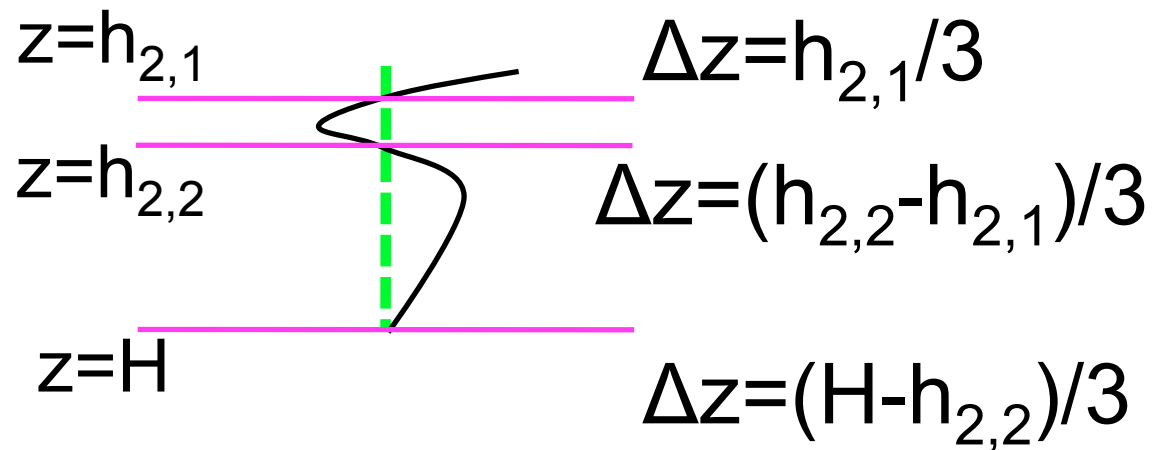
Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings



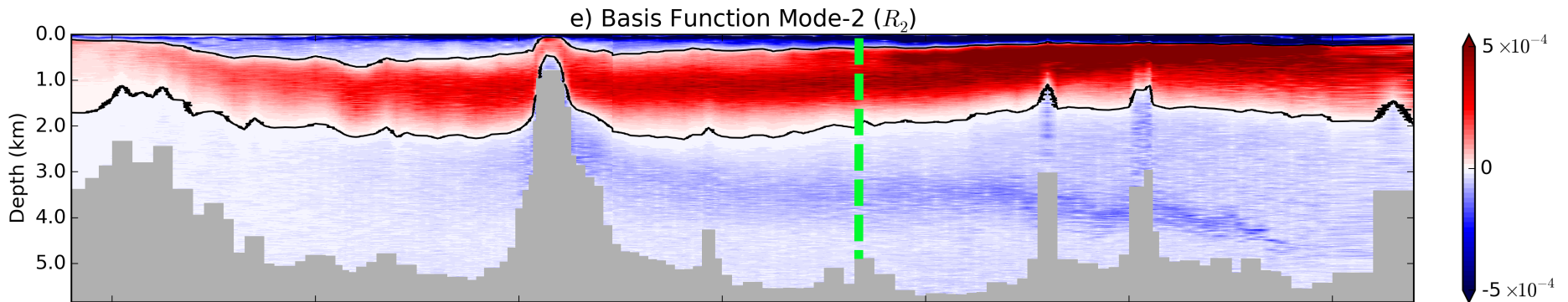
# Determining the vertical structure of horizontal flows. P15: T,S



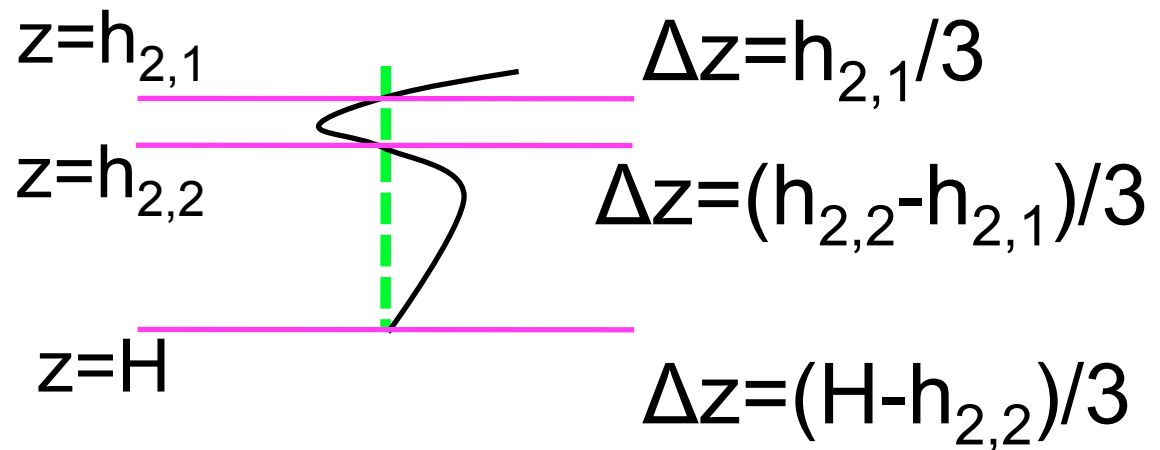
Ensure that there are 3 vertical grid points between zero crossings



# Determining the vertical structure of horizontal flows. P15: T,S

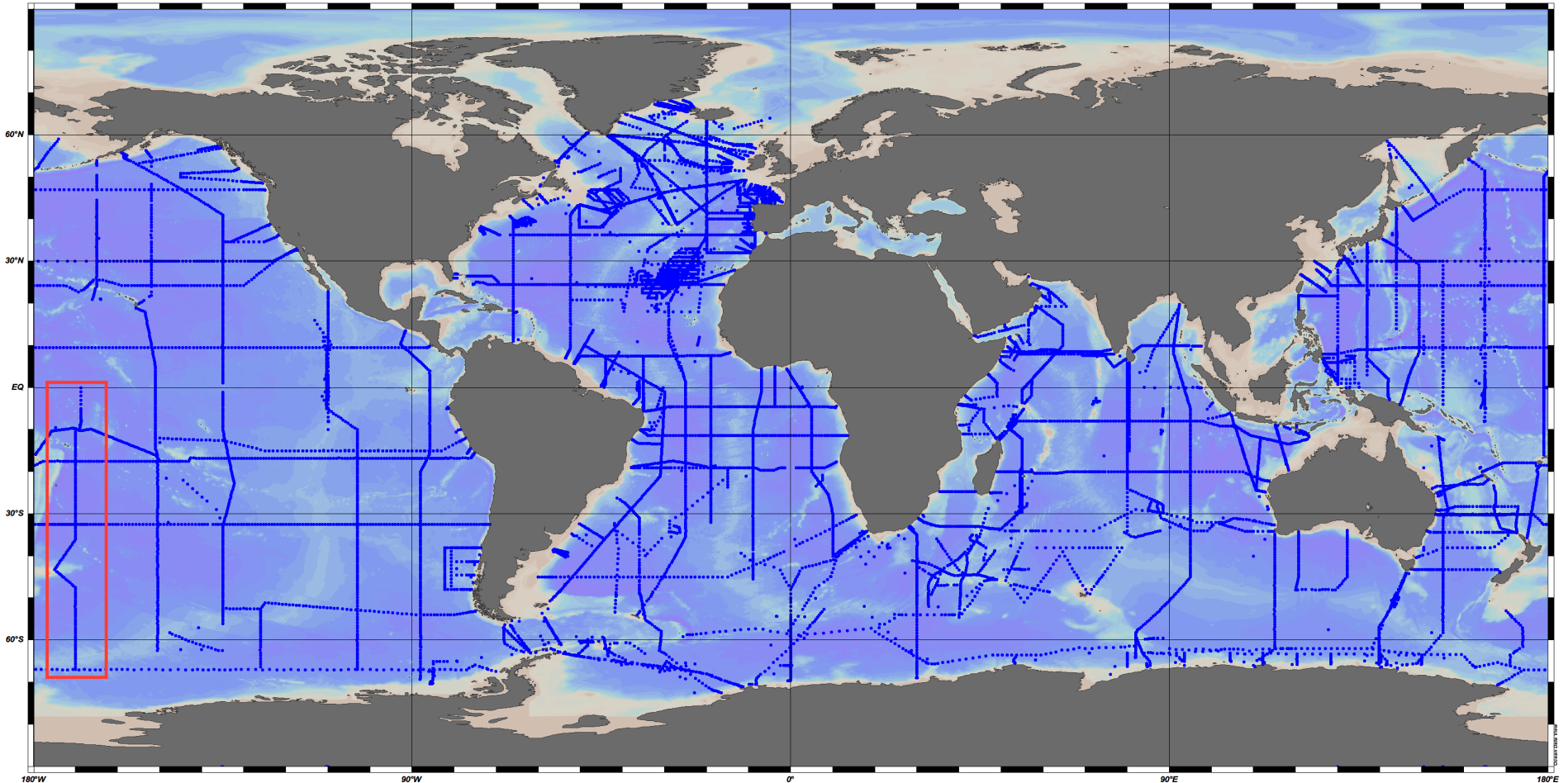


Ensure that there are 3 vertical grid points between zero crossings



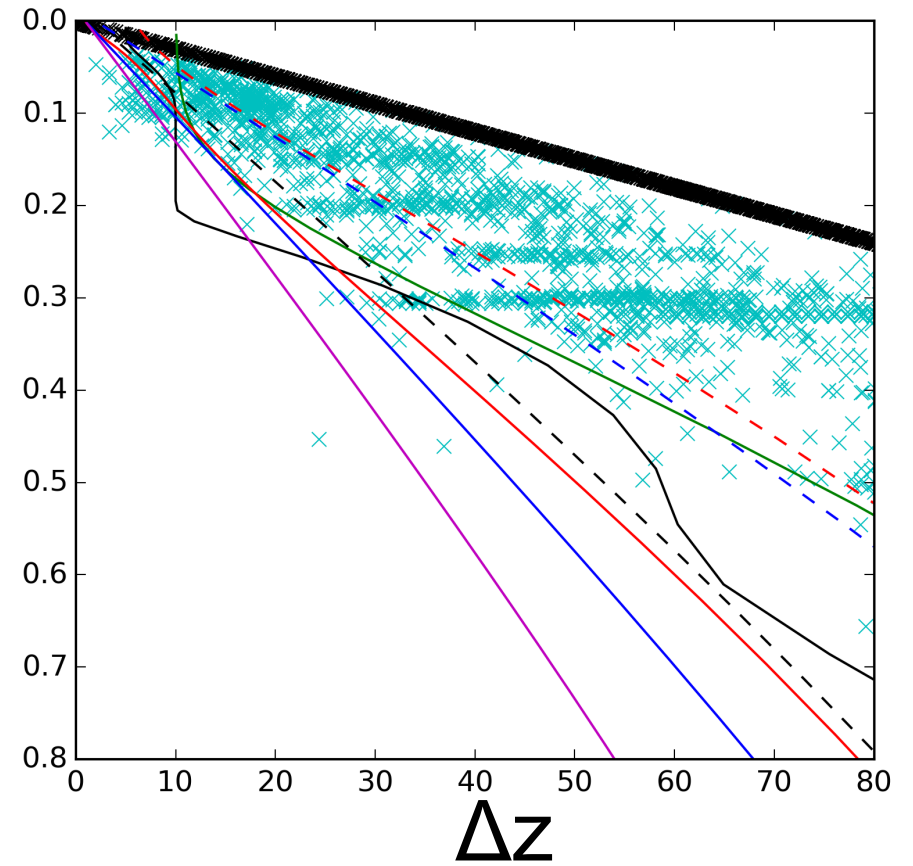
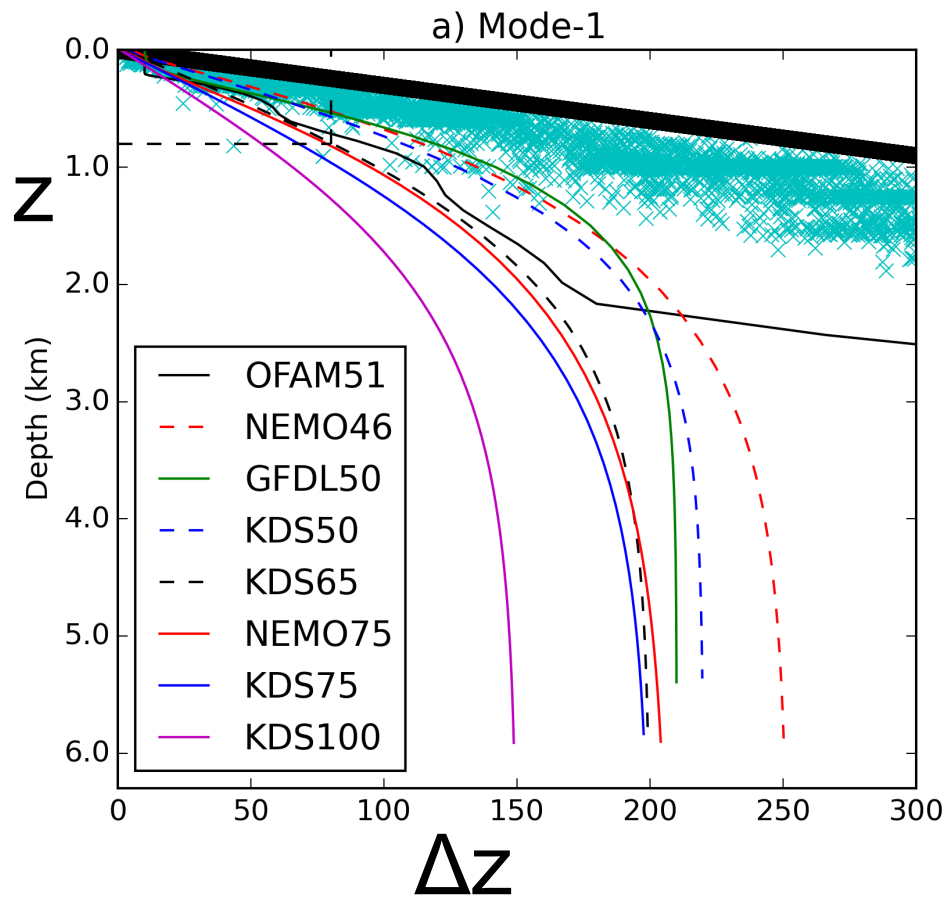
$(z, \Delta z)$  pairs for domain of interest

# WOCE: 18,000 full-depth CTD profiles

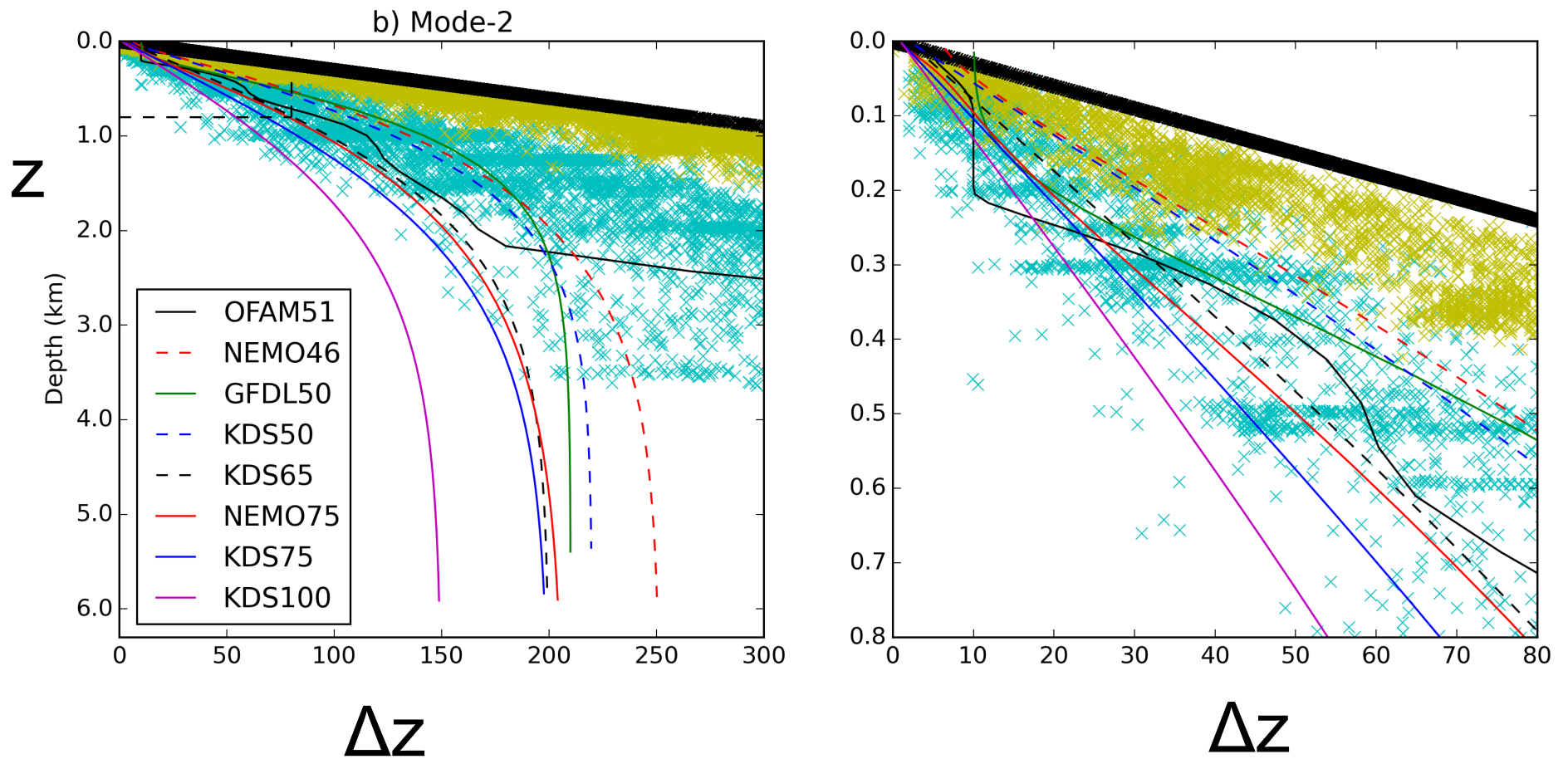


[www.ewoce.org](http://www.ewoce.org)

# $(z, \Delta z)$ pairs for domain of interest



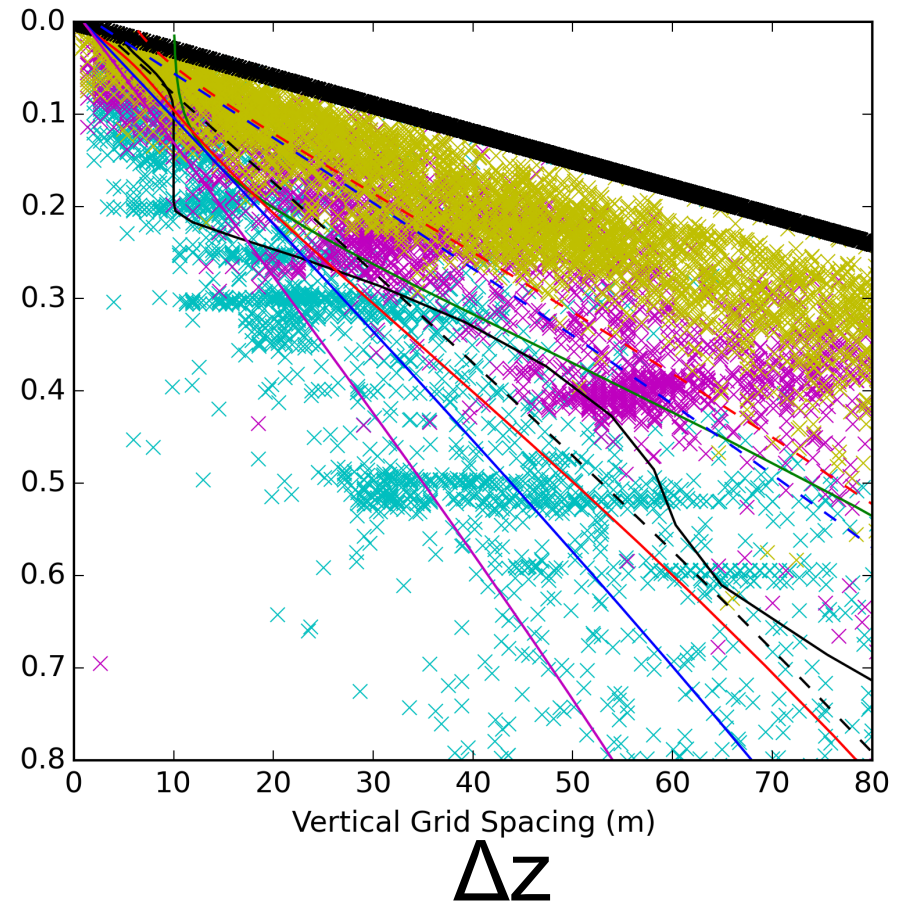
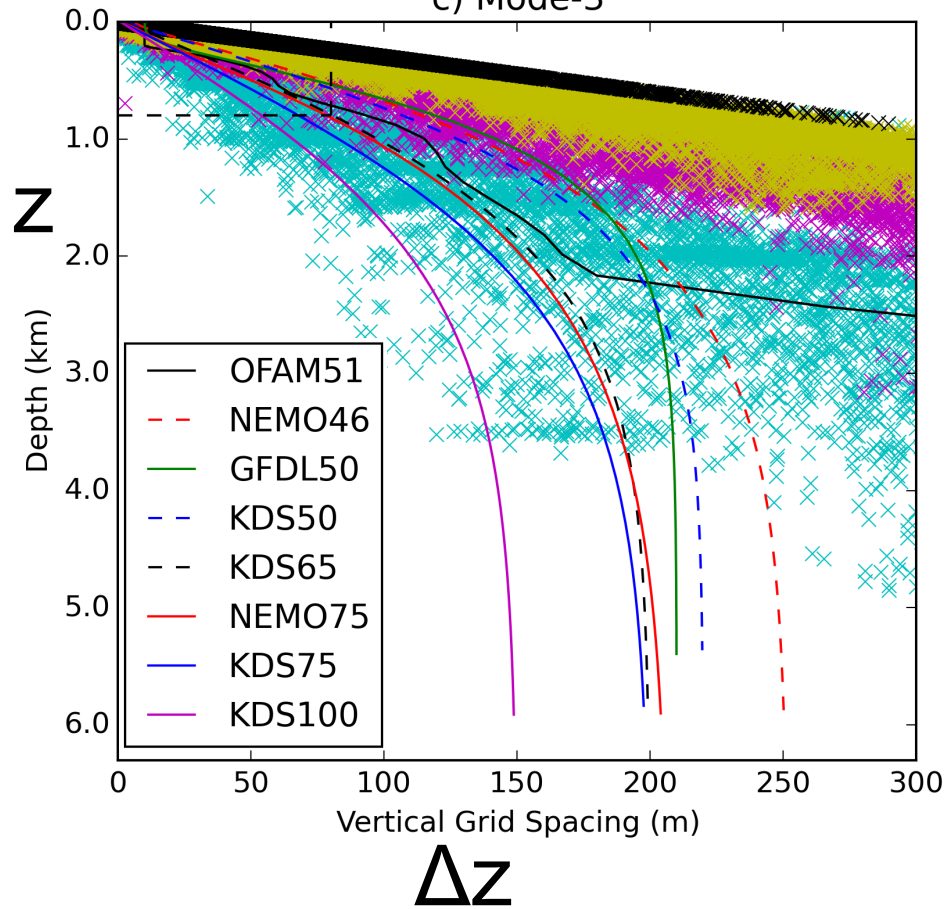
# $(z, \Delta z)$ pairs for domain of interest

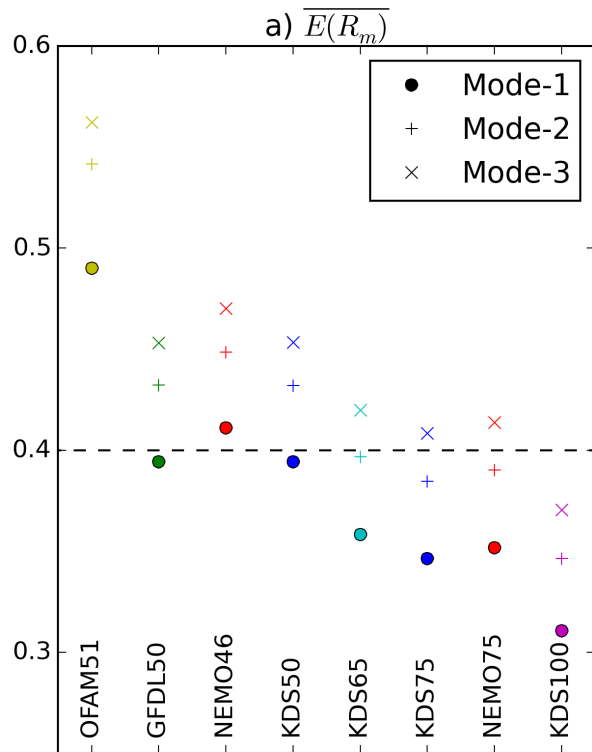




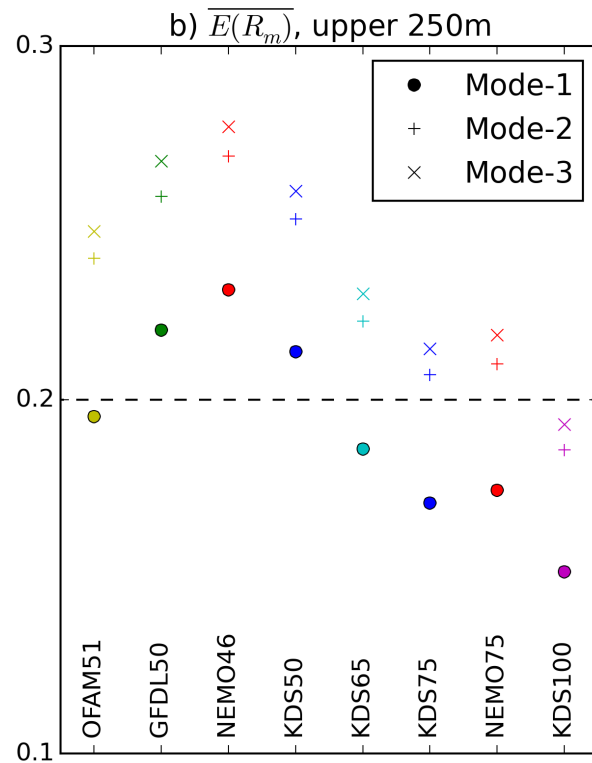
# $(z, \Delta z)$ pairs for domain of interest

c) Mode-3

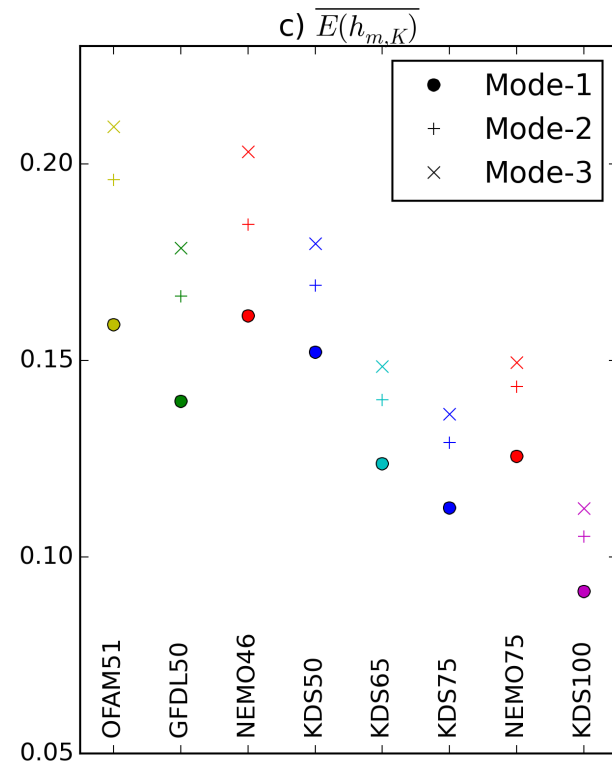




Error of modal structure



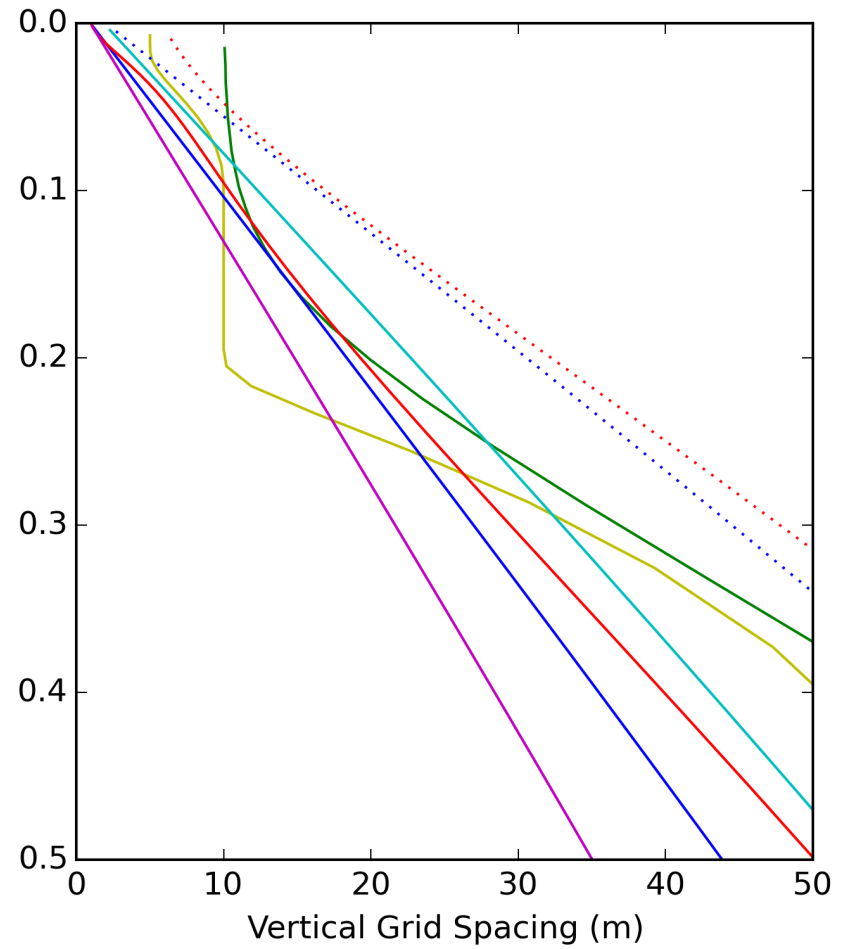
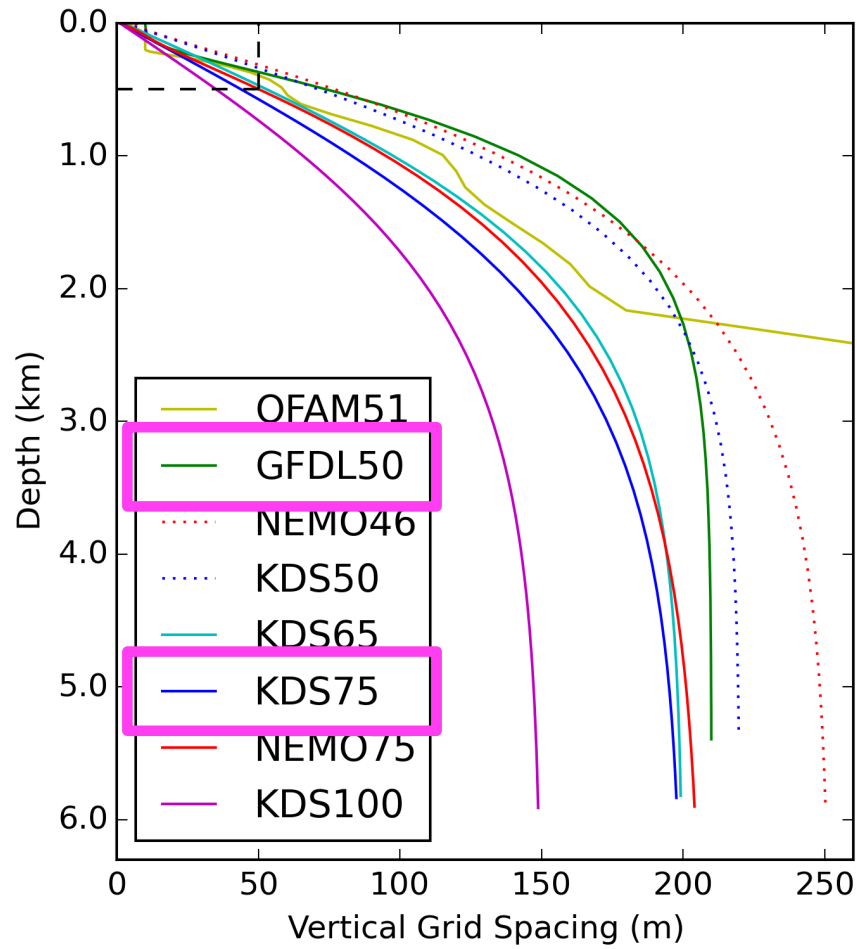
Error of modal structure  
upper 250m



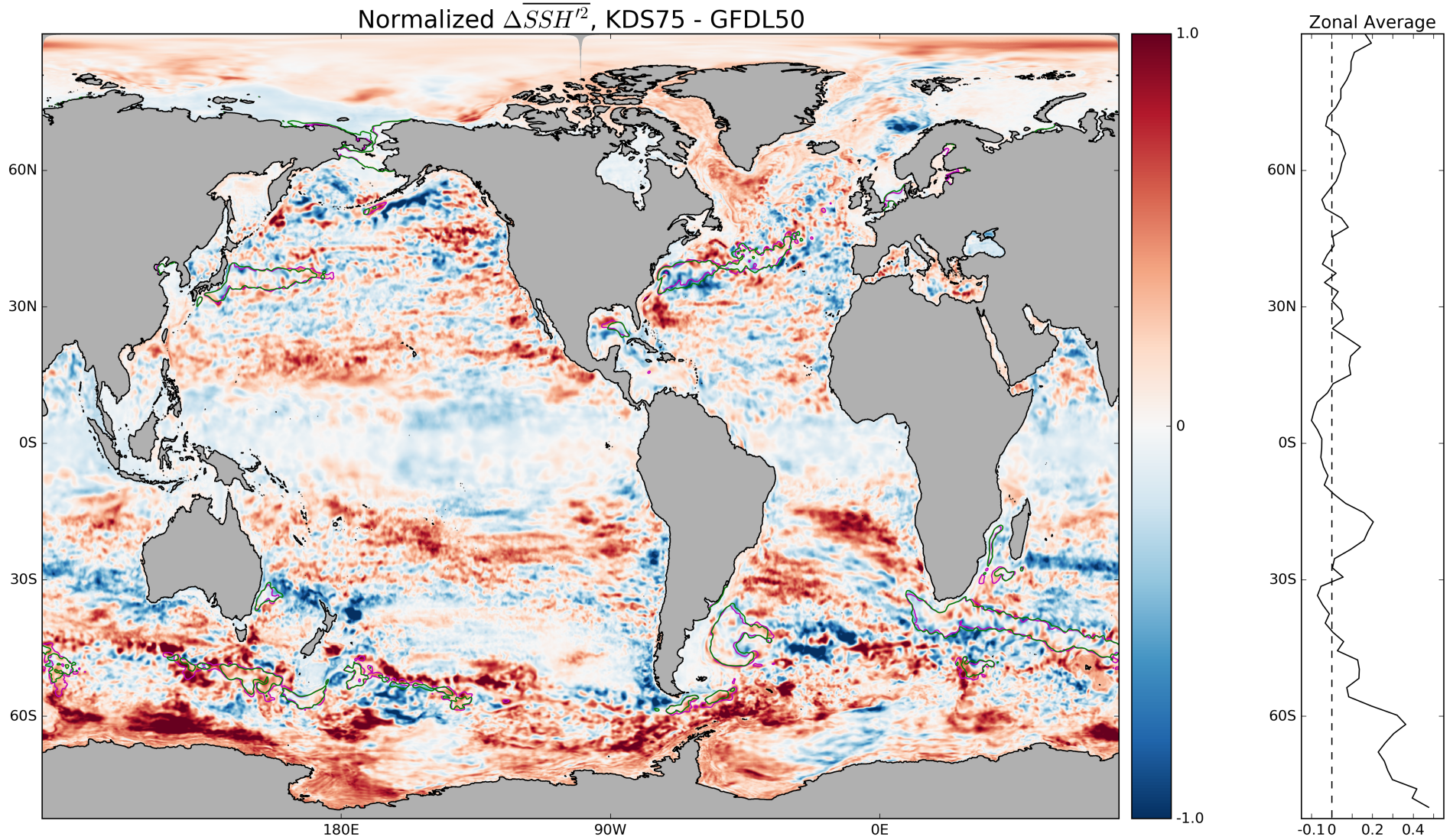
Error of zero crossing  
depths



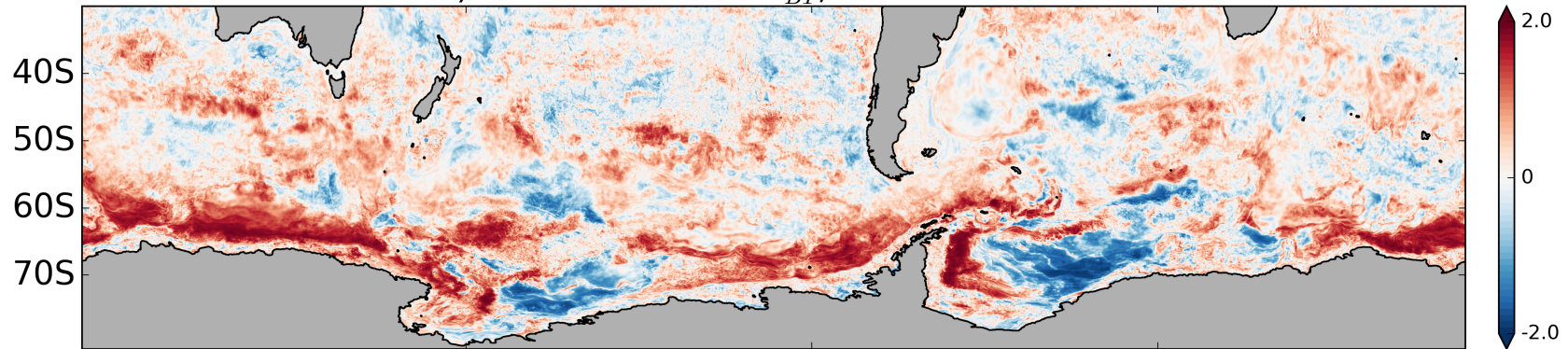
# Vertical profiles of vertical grid spacing



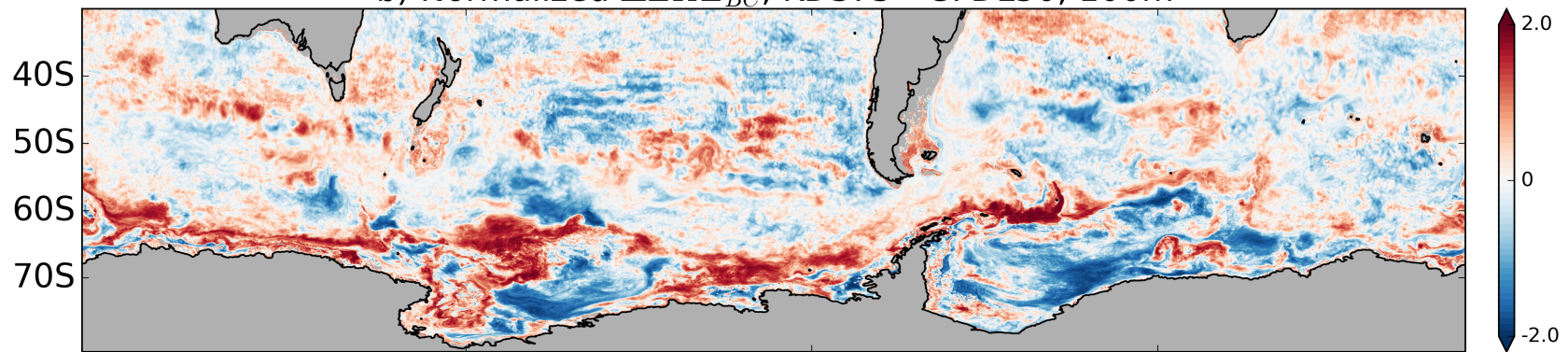
# Normalized sea surface height variability difference



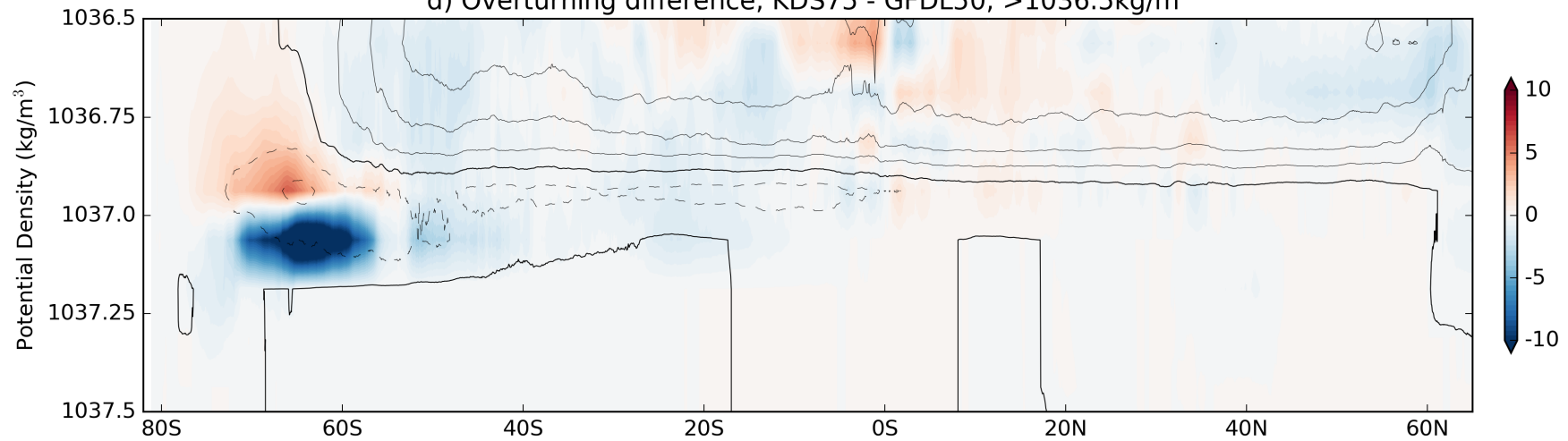
a) Normalized  $\overline{\Delta EKE_{BT}}$ , KDS75 - GFDL50



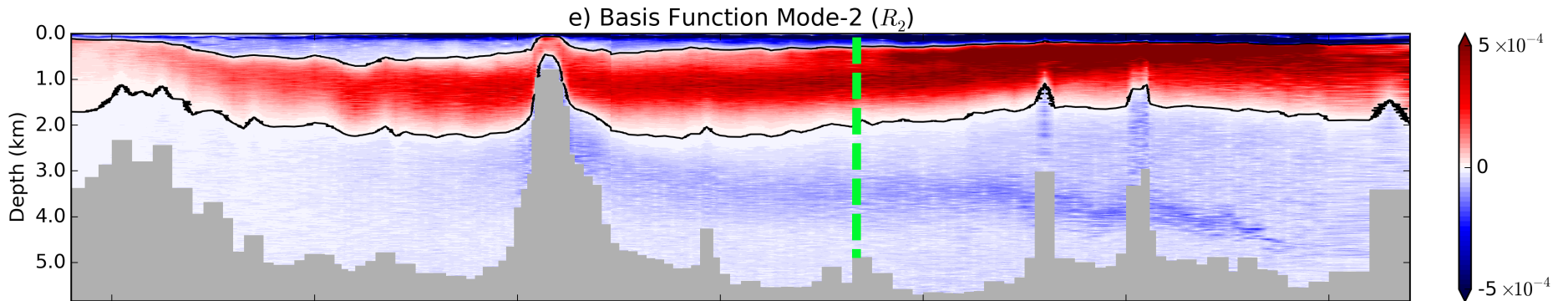
b) Normalized  $\overline{\Delta EKE_{BC}}$ , KDS75 - GFDL50, 100m



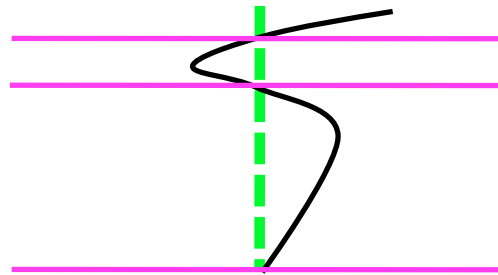
d) Overturning difference, KDS75 - GFDL50,  $>1036.5\text{kg/m}^3$



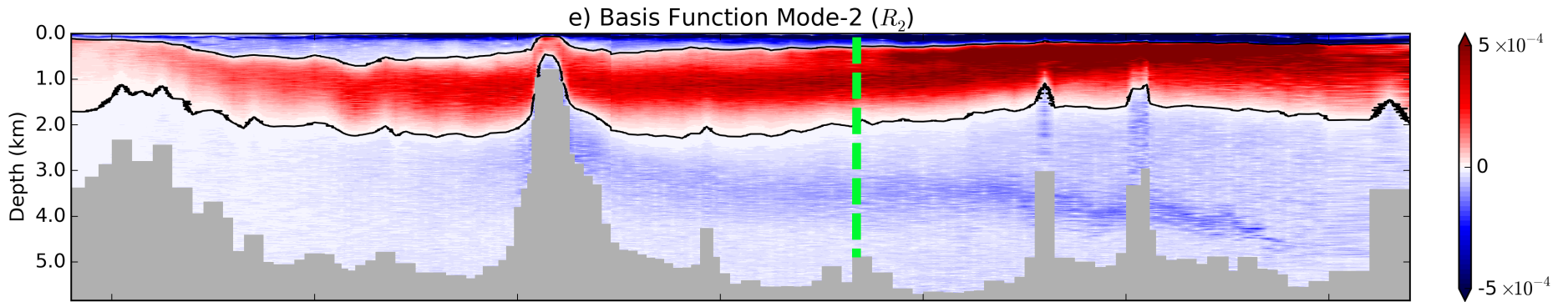
# Sigma coordinates????



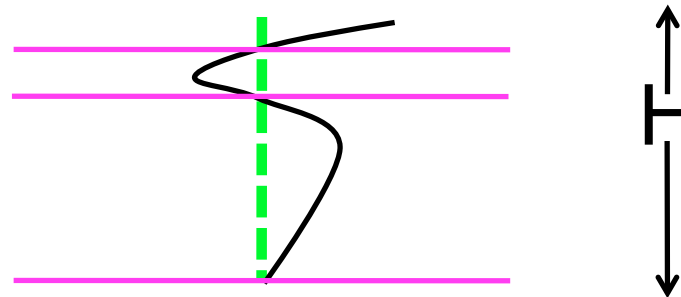
Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings



# Sigma coordinates????

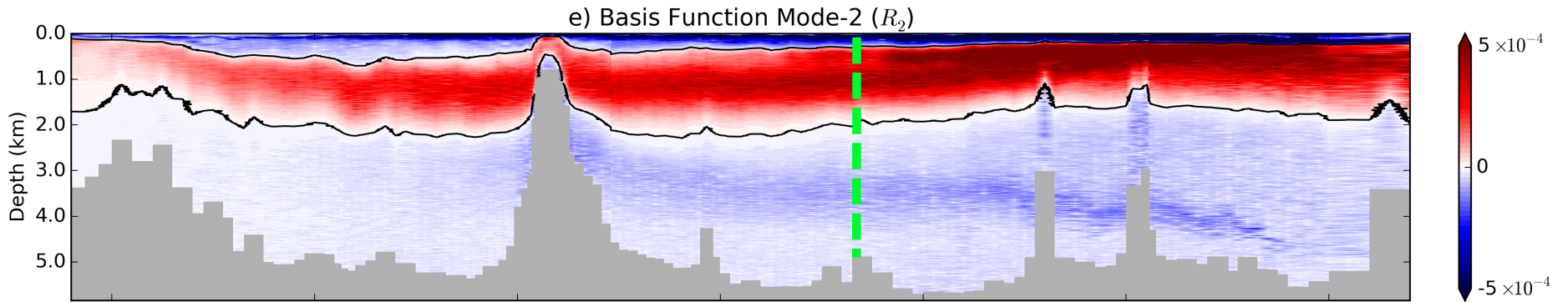


Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings



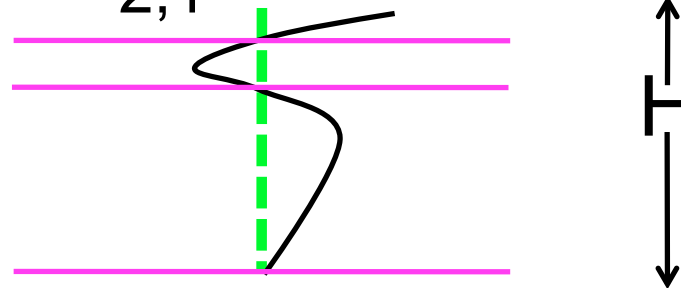


# Sigma coordinates????

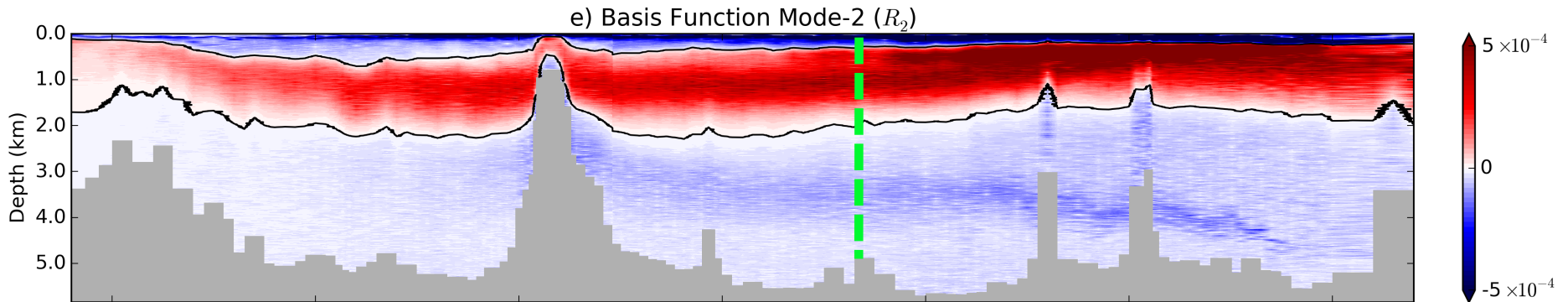


Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings

$$z/H = h_{2,1}/H$$

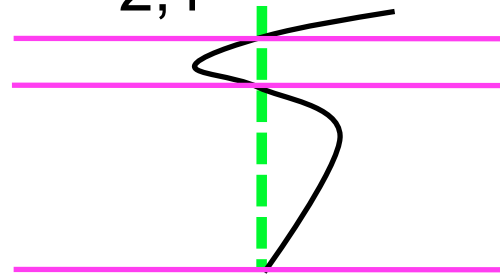


# Sigma coordinates????



Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings

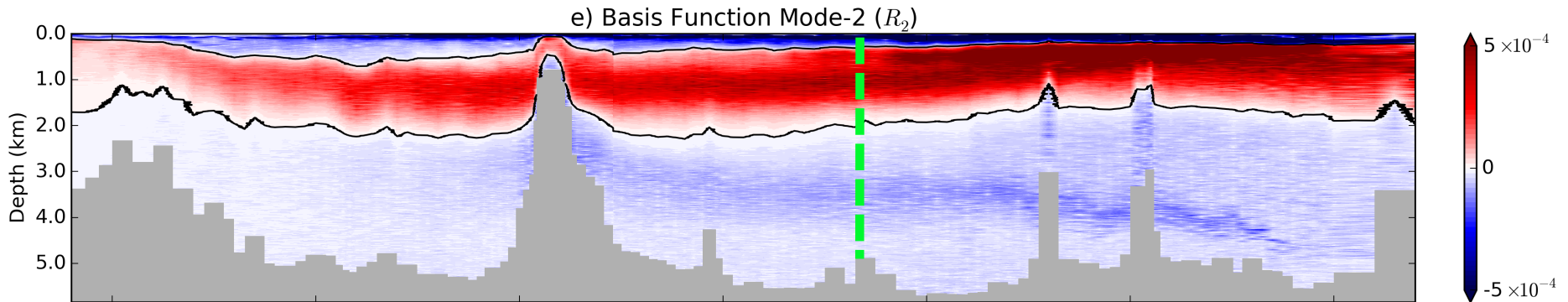
$$z/H = h_{2,1}/H$$



$$\Delta z/H = (h_{2,1})/3H$$

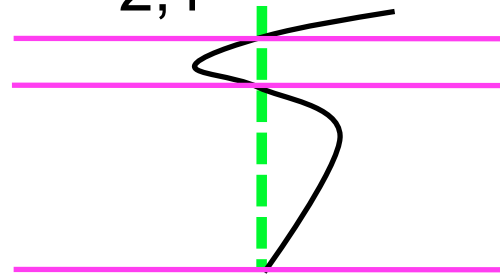


# Sigma coordinates????



Ensure that  
there are 3  
vertical grid  
points  
between zero  
crossings

$$z/H = h_{2,1}/H$$

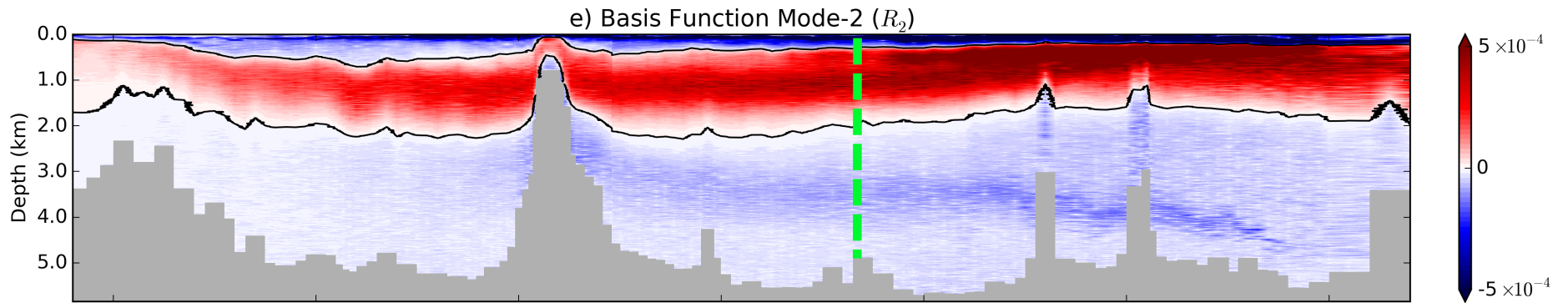


$$\Delta z/H = (h_{2,1})/3H$$



$(z/H, \Delta z/H)$  pairs for domain of interest

Sigma coordinates????



For mode- $m$ ,  $\Delta z/H < 1/6m$

Primary purpose of the vertical grid is to resolve horizontal flows

50 z-levels for first mode, 25 levels per additional mode

Minimise subjectivity in ocean modelling

